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GUGLIELMO MARCONI,

Inventor of the Marconi System
of Wireless Telegraphy.

CYCLOPEDIA

of

Applied Electricity

A Practical Guide for

ELECTRICIANS, MECHANICS, ENGINEERS, STUDENTS, TELEGRAPH AND TELEPHONE OPERATORS, AND ALL OTHERS INTERESTED IN ELECTRICITY

Prepared by a Corps of

EXPERTS, ELECTRICAL ENGINEERS AND DESIGNERS

Illustrated with over Two Thousand Engravings

AMERICAN SCHOOL OF CORRESPONDENCE
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In the preparation of these volumes the editors have received invaluable assistance from the foremost engineering firms and manufacturers. Grateful acknowledgment is here made for the valuable drawings, data, suggestions, and criticisms which have enabled the editors to make these volumes representative of the latest and best practice in the Design, Construction, and Operation of Electrical Machinery and Instruments.

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Preface

REALIZING the great need for a more scientific knowledge of electricity on the part of thousands of practical men of limited technical education, an attempt has been made in the following pages to give a presentation of the subject which shall be easily understood by such men, and at the same time, cover all the essential principles and methods. The principles usually deduced by higher mathematics are here made clear by careful explanation and a large number of diagrams drawn especially for the text. Numerous engravings exemplify modern practice, and form a pictorial index to the latest and best methods of applying electricity to lighting, railways, power transmission, machine tools, etc.

¶The Cyclopedia of Applied Electricity is based upon the method which the American School of Correspondence has developed and successfully used for many years in teaching practical electricians the scientific principles underlying their work. It is compiled from the most valuable of the School's Instruction Papers and forms a simple, practical, concise, and convenient reference work for the shop, the library, the school, and the home.

¶The success which the American School of Correspondence has attained in teaching thousands of electricians is in itself the best possible guarantee for the present work. Therefore, while these volumes are a marked innovation in technical literature, representing as they do the best methods of a large number of *different* authors, each an acknowledged authority in his work,—they are by no means an experiment, but are in fact the e[illegible]f the most successful method yet devised for the education of the busy working man.

¶Among the sections of most practical value are those on Alternating Current Machinery, Storage Batteries, Electric Wiring, Lighting, etc. In these pages the authors have succeeded in presenting the subjects in such manner as to overcome the hitherto insurmountable obstacle—higher mathematics. The rules and formulae are presented in a very simple manner, and special effort has been made to illustrate every principle by diagrams and practical examples.

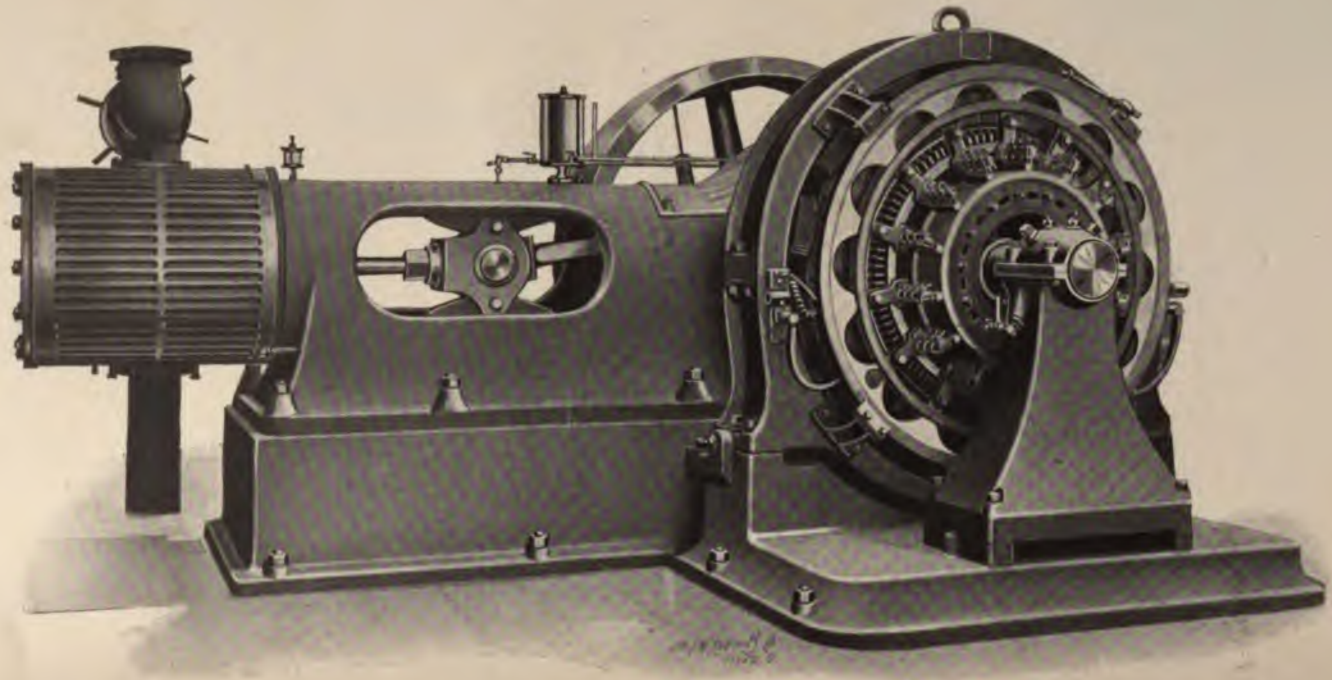
¶Numerous examples for practice are inserted at intervals; these with the test questions, help the reader to fix in mind the essential points, thus combining the advantages of a textbook with a reference work.

¶Grateful acknowledgment is due to the corps of writers and collaborators who have prepared the many sections of this work. The hearty co-operation of these men—engineers of wide practical experience, and teachers of acknowledged ability—has alone made these volumes possible.

¶The Cyclopedia is published in the belief that it will meet a real need among designers, constructors and operators of electrical machinery. That it may save many weary hours of search among the scattered textbooks and reference works of the day,—books which being intended largely for college-trained men are necessarily far from meeting the needs of the average practical man, is the hope of the compilers and publishers.

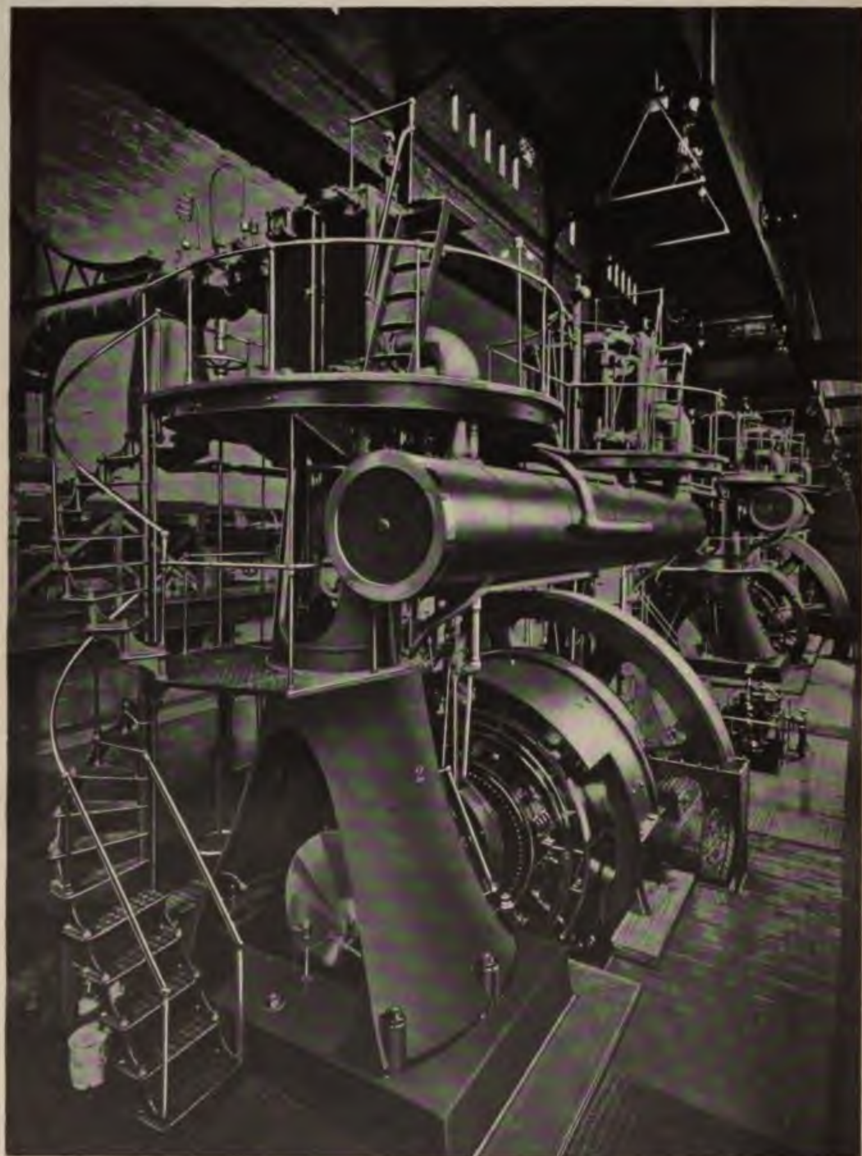
Contents

PART I.



22" × 22" McEWEN ENGINE. 250 K.W. THOMPSON-RYAN DYNAMO.

Ridgway Dynamo and Engine Co.



METROPOLITAN WEST SIDE ELEVATED RAILWAY CO., CHICAGO.

ELEMENTS OF ELECTRICITY.

Electricity is an invisible agent which manifests itself in various ways. The precise nature of electricity is not known, but the effects produced by it, the methods of controlling it, and the laws governing its action are becoming well known.

Electricity may be considered under three heads: first, **magnetism,** — second, **static** electricity (where it appears as a *charge* upon bodies),— and third, — **dynamic** electricity (where it appears as a *current*). The sciences which treat of the two latter branches are called *electrostatics* and *electrodynamics* respectively. These divisions of the subject, although covering manifestations widely different, are closely related.

MAGNETISM.

Natural Magnets. Substances which have the property of attracting pieces of iron are called *magnets*. A material possessing this property was first found by the Ancients at Magnesia, in Asia Minor, from which fact arose the name *magnet*. The natural magnet is an oxide of iron and is also called the *lodestone*. It is widely distributed in different parts of the world, but is not always found possessing magnetic properties.

Artificial Magnets. When a bar of hard steel is rubbed with a lodestone, the steel will acquire the same magnetic property and to a much greater extent. Such artificial magnets are therefore always used in place of lodestones.

Poles. When one end of a magnet is placed in iron filings and afterwards withdrawn, the filings are attracted and cling to it in great numbers. This is illustrated in Fig. 1. The filings would be attracted to the opposite end and would cling to it in the same way if it were placed in the filings. The middle of the bar, however, does not have this property, and toward the ends the power rapidly increases. The ends of the magnet, where the attraction is the greatest, are called *poles*.

A common example of a magnet is the compass needle. It is well known that such a needle always places itself so as to point north and south, and that the same pole always points toward the north. This is called the *north seeking pole*, while the other is called the *south seeking pole*, or simply the north and south pole respectively.

In the experiment with iron filings either of the magnetic poles

Fig. 1.

attracts them and there is apparently no difference between the two poles. That there is a difference, however, may be shown by experimenting with two compass needles. If the north poles of two such needles be brought near each other, they will be *repelled*. In the same way the south poles will repel each other. But when

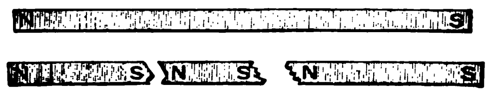


Fig. 2.

the north pole of one needle is brought near the south pole of the other, *attraction* takes place. This shows that *like poles repel* each other, while *unlike poles attract* each other.

The fact that a compass needle always points north and south, or approximately so, is because the earth itself is a great magnet. The magnetic poles of the earth coincide very nearly with the geographical north and south poles. The geographical north pole of the earth is unlike the north pole of a magnetic needle, and hence attracts it.

The two poles always exist in a magnet. If, as illustrated in Fig. 2, a single magnet be broken into several parts, the separate parts will then become individual magnets. Each portion will have the same properties which the magnet as a whole possessed. When the separate parts are placed together again the many poles of the small portions will neutralize each other and the complete magnet will act as before

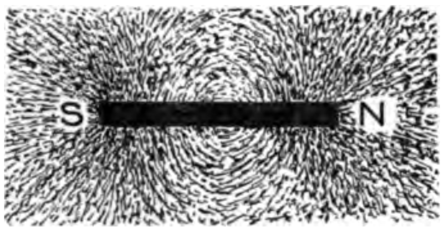


Fig. 3.

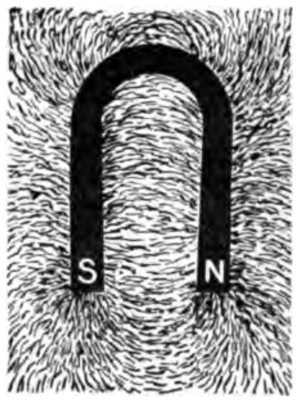


Fig. 4.

Magnetic Field. The space surrounding a magnet, called the field, is subject to the influence of the magnet and is called its *magnetic field*. The presence of such a field may be shown by a simple experiment.

Suppose a sheet of paper be placed upon a bar magnet and iron filings spread evenly upon the paper; by tapping the paper lightly, the filings will form into a series of curved lines extending from one pole to the other. The form of these curves for a bar magnet is illustrated in Fig. 3. The formation of these definite curves indicates that the magnetic field exerts its influence in certain definite directions which are called the *lines of magnetic force*, or simply *lines of force*. The field of a horseshoe magnet is represented in Fig. 4, and that about the end of a bar magnet is represented in Fig. 5.

Magnetic Induction. It is because of this magnetic field that magnets have the power of attracting pieces of iron. When a piece of iron is brought under its influence, it becomes a *temporary* magnet, and for the time being has its two poles. If the north pole of the permanent magnet is adjacent to the piece of iron, a south pole will be induced in the iron next to this north pole and a north pole in the portion farthest from it. The attraction is then exactly similar to the attraction between two permanent magnets when unlike poles are brought together. This action of developing magnetism in iron is called *magnetic induction.*

The attraction of iron is therefore due to the fact that the

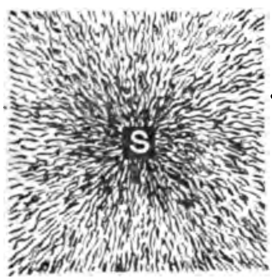


Fig. 5

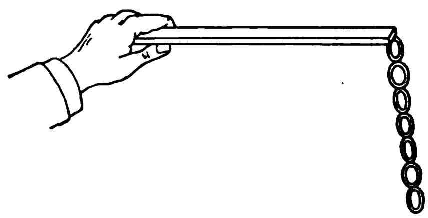


Fig. 6.

magnet first magnetizes it and then attracts it. When the iron is withdrawn from the magnetic influence it loses its magnetism. The experiment illustrated in Fig. 6 proves this to be true. When the upper ring of soft iron is placed in contact with the bar magnet it becomes a magnet, having, say, a north pole at the top and a south pole at the bottom. When another ring is added, the first will in turn induce a north pole at the top and a south pole at the bottom of the second ring. When other rings are added, a similar action takes place and all the rings are supported. If, however, the first ring be removed, the others will immediately drop and will lose their magnetism.

Magnetic induction explains the formation of tufts of iron filings which become attached to the poles of magnets. The filings are temporarily converted into magnets; these act inductively on the adjacent parts, these again on following ones, and so on, causing them all to be attracted. They have a bush-like appearance, which is due to the repulsive action that the outside free poles exert upon each other.

The attraction is greatest when the iron is in contact with the magnet, but actual contact is unnecessary to cause attraction. A sheet of glass, paper or wood, etc., may be placed between the magnet and the iron, and attraction will still be present.

Magnetic Substances. Substances which are attracted by magnets when either pole is presented to them are called *magnetic substances.* Besides iron are included steel, nickel and cobalt in this class. A magnet is attracted or repelled by another magnet according to whether the poles near each other are unlike or like, but magnetic substances are always attracted.

Retentivity. After a piece of soft iron is once magnetized it will, when removed from the influence of the magnet, lose substantially all of its magnetism. On the other hand, a piece of steel or nickel will not be magnetized as much as soft iron, but will afterwards retain much of its magnetism. It resists being magnetized, and afterwards resists being demagnetized. This power of resisting magnetization or demagnetization is called *retentivity.* Steel has much greater retentivity than wrought iron, and the harder the steel the greater is the retentivity.

Methods of Magnetization. Permanent magnets are usually made from steel, and the following are the common methods of magnetization:

Magnetization by *single touch* consists in moving the pole of a powerful magnet from one end to the other of the bar to be magnetized, and repeating this operation several times, always in the same direction. The end of the bar touched last by the magnet becomes of opposite polarity to the end of the magnet by which it has been touched. This method produces only a weak magnet, and is therefore used for small magnets only.

Magnetization by *divided touch* consists in placing the two unlike poles of two magnets at the middle of the bar to be magnetized, and in moving them simultaneously towards the opposite ends of the bar. Each magnet is then placed in its original position and the operation repeated. The bar becomes magnetized after repeating this several times on both faces of the bar.

In magnetization by *double touch* the two magnets are placed as before, with opposite poles near each other, at the middle of the bar to be magnetized. Instead of moving them in opposite directions toward the ends, they are kept at a fixed distance apart by means of a piece of wood between them, and are simultaneously moved first towards one end and then back towards the other, repeating several times and stopping at the middle.

Magnets lose much of their magnetism when subjected to knocks or jars.

STATIC ELECTRICITY.

Friction as a Source. There are several sources of electricity, such as friction, chemical action, heat and induction. Friction as a source of electricity will now be considered. This relates to electricity existing as *charges* upon bodies, and is known as *static electricity.*

When a glass rod or stick of sealing-wax is rubbed with a piece of flannel or silk, each acquires the property of attracting light bodies such as pieces of wool, paper, gold leaf, etc. After coming into contact with such substances, however, they will be repelled. This may be well observed by employing a pith ball suspended by a fine thread, as shown in Fig. 7. When the rod of glass or wax is brought near the ball it is strongly attracted. After contact is made, the ball will be strongly repelled.

This repulsion is explained by the fact that when contact is made between the ball and rod, the ball receives part of the electricity from the rod. Both are then charged with the same kind of electricity, and the repellant action shows that two bodies thus charged, repel each other.

Positive and Negative Electricity. Repulsion does not always take place between bodies charged with electricity. Either a stick of sealing-wax or a glass rod after being rubbed with silk will attract the pith ball until contact has been made, and then will repel it. The electricity developed in each of these cases, however, is not the same. After the pith ball has been touched with an electrified glass rod, it will be *attracted* by the electrified stick of sealing-wax; or if touched by the latter, it will be repelled by it, but will be *attracted* by the glass rod. Such phenomena are explained by assuming that there are two kinds of electricity, which have been designated as ***positive*** (+) and ***negative*** (—) electricity.

When the glass rod is rubbed with silk it is said to possess a positive charge, and when the wax is rubbed it is said to possess a negative charge. The pith ball having been touched by the glass rod is charged positively, and is therefore attracted by the negatively charged sealing-wax, or upon receiving a negative charge from the wax, it will be attracted by the glass.

This action is expressed in the following law:

Electric charges of the *same* sign *repel* each other; those of *opposite* sign *attract* each other.

Production of Both Positive and Negative Electricity. When two substances are rubbed together neither positive nor negative electricity is produced alone, but both are produced at the same time and in equal quantities. After the friction, a positive charge is found to exist upon one surface and a negative charge upon the other and in equal quantities. In the case of glass being rubbed by silk, the glass acquires a positive charge and the silk a negative charge. That the charges are equal is proved by the fact that if both of these charged bodies are presented to the pith ball at once, the latter will be neither attracted nor repelled. Also if the charges of both the glass and silk are imparted to a third body, the third body will have no resultant charge, since the two quantities of electricity being equal and of opposite sign, neutralize each other.

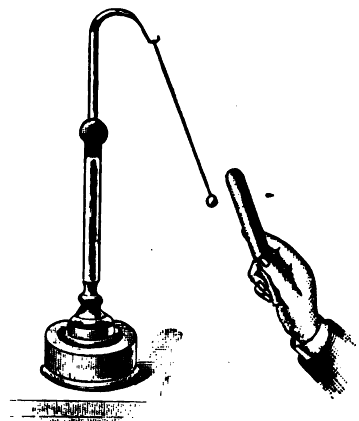


Fig. 7.

Whether a body receives a positive or negative charge depends upon the material of the body with which it makes contact. Thus glass when rubbed by silk is p[illegible]ively charged, but when rubbed by wool the glass is neg[illegible]l. In the following list the arrangement is such that each substance, when rubbed by one following it, will be positively electrified, but when rubbed by one preceding it, will be negatively electrified: Fur, wool, ivory, glass, silk, wood, metals, sealing-wax, sulphur, india-rubber, celluloid.

Conductors and Insulators. *Conductors* are substances which readily allow electricity to pass from one portion of them to another; that is, they readily conduct electricity. *Insulators*, or non-conductors, are those substances which do not allow such free passage of electricity, or which offer a certain *resistance* to its passage. If one end of a glass rod is rubbed with silk or wool, the end so rubbed will be electrified, but the other end will possess little or no charge. The electricity is not freely conducted from one part to another. When a metallic substance is charged, however, the electricity will be distributed uniformly over its surface. All substances offer a certain amount of resistance to the passage of electricity and no body entirely prevents its passage; that is, there is no perfect conductor, and there is no perfect insulator.

There is no definite line of distinction between conductors and insulators, and some substances are neither, but may be termed semi-conductors or partial conductors. The ability of a body to conduct electricity, that is, its *conductivity*, also depends upon its physical condition. For example, the conductivity of most bodies depends largely upon the temperature. The following list of substances is arranged in the order of increasing resistance.

Conductors.	*Partial Conductors.*	*Insulators.*
Silver	Cotton	Oils
Copper	Dry wood	Porcelain
Other metals	Marble	Wool
Charcoal	Paper	Silk
Water		Resin
The body		Guttapercha
		Shellac
		Ebonite
		Paraffin
		Glass
		Air

From the preceding it is evident that silver is the best conductor and air is the best insulator. Copper, on account of being an excellent conductor and comparatively cheap, is used almost entirely for conducting electricity from power stations or from one point to another. Marble is a comparatively poor conductor and is therefore largely used for switchboards. Porcelain and glass, being good insulators and having other desirable properties are much used for insulating conductors from their main supports. Water is a fairly good conductor, and considerable difficulty is consequently experienced in securing good insulation in damp places.

Distribution of Charge. An electrical charge upon a conducting body is distributed over its *surface*. That it does not reside *within* the body may be shown in several different ways. For example, it is immaterial whether the inside of a conductor is composed of wood or glass, or if the conductor is hollow; the charge in any case is distributed over its surface.

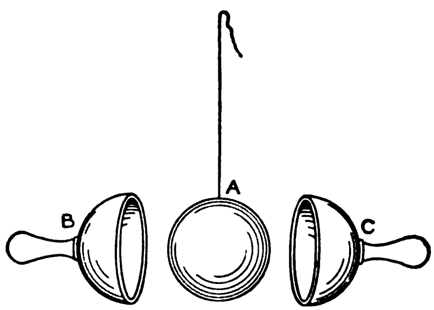


Fig. 8.

The ball *A* and covers *B* and *C*, shown in Fig. 8, may be used to prove this. Suppose the covers to be placed over the ball and the whole to be electrified. When the covers are removed, the entire charge will be found to remain with them, and none will exist upon the ball.

Suppose the hollow sphere in Fig. 9 to be charged. If a conductor be inserted through the aperture and brought in contact with the inside of the sphere and afterwards carefully withdrawn, it will be found that it has received no charge. If touched to the outside, however, the conductor will receive part of the charge. The conductor used for this purpose may be a thin piece of metal attached to an insulating handle. A metallic cylinder, even of wire gauze, may be used in place of the sphere. To prevent the charge from passing to the earth, the cylinder or sphere must be insulated from the earth by a glass standard

We have seen that bodies charged with electricity of like sign repel each other. This may be taken as the explanation of the fact that a charge resides upon the surface. As it tends to repel itself, the charge resides as far from the centre of the body as possible.

Static Influence. When a charged body is placed near bodies in a neutral state, it will act upon them in a manner similar to that of a magnet upon soft iron. This action is said to be due to influence or to *electrostatic induction.*

Induction of this nature may be made evident by means of a metal cylinder supported on a glass standard, as shown in Fig. 10. The cylinder is supplied at each end with a pith ball suspended by a thread. Suppose a sphere charged with positive electricity and mounted upon an insulating standard be brought near one end of the cylinder; the pith balls will at once fly outwardly, showing that the cylinder is then charged. If the sphere is removed, the pith balls will fall towards the ends of the cylinder again, showing that it is once more in the neutral state. Throughout this action the sphere has neither gained nor lost in the amount of its charge. Upon testing the temporary charge on the cylinder, it will be found that at the end near the sphere the electricity is negative while that at the distant end is positive.

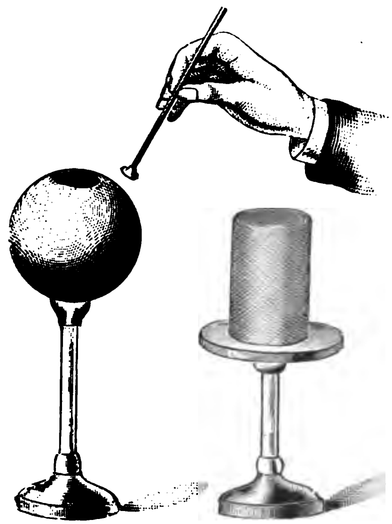


Fig. 9.

Bodies charged with electricity are surrounded by an electric field in the same way that magnets are surrounded by a magnetic field. With this in mind, the above experiment may be easily understood. When the charged sphere is brought near the cylinder, the latter comes under the influence of the former's field. The lines of force from the sphere will pass to the cylinder, and therefore cause its electrification. Since unlike charges attract each other and like charges repel each other. the sphere attracts a negative charge to the near end and repels a positive charge to the distant end of the cylinder. When the sphere is removed, the induced positive and negative charges neutralize each other. If the sphere possessed a negative charge, there would then be induced a positive charge at the near end and a negative charge at the distant end of the cylinder. The middle portion of the cylinder, however, remains neutral, and the strength of the charges increases gradually towards the ends. If the cylinder be separated into two parts while under the influence of the charged body, the induced charges cannot unite after the removal of the sphere, and will then retain their charges.

In the experiment illustrated by Fig. 10, there is consider-

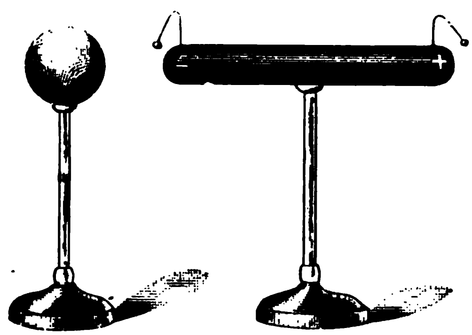


Fig. 10.

able attraction exerted between the sphere and cylinder. The unlike and adjacent charges attract each other, but the like charges on the sphere and distant end of the cylinder repel each other. As the unlike charges are nearer each other than the like charges, the attraction overbalances the repulsion and there is a resultant attraction. This action is the same in effect as that of magnets upon soft iron. There is first the induction and then the consequent attraction.

The greater the charge possessed by the sphere, the greater will be the induced charge upon the cylinder. Also, the nearer the two bodies are placed to each other, the greater becomes the charge upon the cylinder, but the induced charge can never exceed that on the sphere.

When the distance between the sphere and cylinder is grad ually decreased, the attraction between the unlike charges is increased. This will continue until the attraction is so great that the unlike charges abruptly unite, and in so doing cause a spark to appear in the small intervening space. The unlike charges are thus neutralized, but the repelled charge will still remain upon the cylinder.

Free and Bound Charge. The two charges induced in the cylinder may be called free and bound charges. The unlike induced charge, which is represented as negative in Fig. 10, is referred to as the bound charge, because it is attracted by the charge upon the sphere and is thus confined. The repelled charge, however, may escape by any path which is offered, and is therefore called the free charge. Hence if contact be made between the cylinder and the earth, the repelled charge will pass to the ground and the attracted charge will remain. If the contact with the earth is then broken and the sphere removed, a resultant charge will remain upon the cylinder, which will be opposite in kind to that of the sphere. This resultant induced charge will then distribute itself uniformly over the cylinder and may be used to induce other charges.

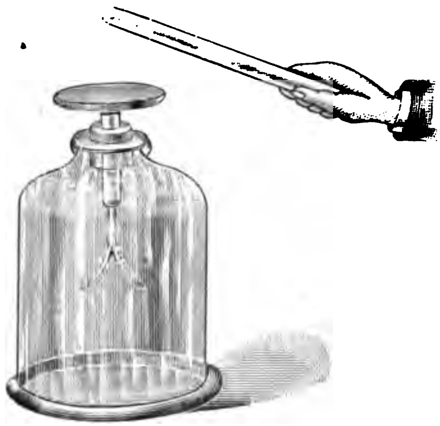


Fig. 11.

When bodies are thus charged by induction, the charge is always opposite in kind to that inducing it. On the other hand, when bodies are charged by conduction or by making direct contact, the charge imparted is of the same kind. Poor conductors are not readily acted upon by induction, since they present great resistance to the passage of electricity.

Electroscope. An electroscope is an instrument used for detecting the presence and determining the kind of electricity in any body. The gold-leaf electroscope shown in Fig. 11 is one of the common forms, and is a very sensitive instrument. It

consists of a glass jar with a metal rod passing through the stopper and terminating at the lower end in two strips of gold leaf, and at the upper end in a metal plate or knob.

When a charged body is brought near the plate, an unlike charge is induced therein, while a like charge is repelled to the two strips of gold leaf. The two strips, being then similarly charged, repel each other and diverge. When the charged body is withdrawn, the strips will come together again. A rubbed glass rod will cause the strips to diverge even when two or three feet from the plate.

In order to determine the kind of electrification a body possesses, the plate is first touched by a body charged with a known kind of electricity, say positive. The electroscope is then charged with positive electricity and the strips of gold diverge. The body to be tested is then brought near the plate. If the gold leaves then diverge more, the body is charged with positive electricity, but if they approach each other, the body is charged with negative electricity.

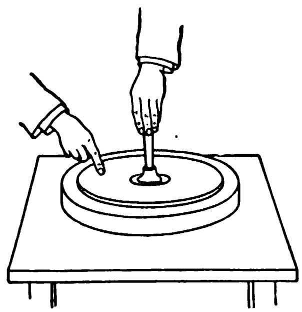


Fig. 12.

Electrophorus. This is an apparatus by which an unlimited number of charges may be obtained from a single charge. It consists of a round cake of resinous material (Fig. 12), formed in a shallow metal pan, and a round metal plate of slightly smaller diameter, provided with a glass handle. In using the electrophorus, the resin is first rubbed with a woolen cloth or with a cat's skin, and receives a charge of negative electricity. The plate is then placed on the cake. Owing, however, to the unevenness of the resin, the plate comes in contact with only a few points, and on account of the non-conductivity of the resin, the negative electricity of the cake does not pass to the plate. On the contrary, it acts by induction on the plate and attracts a positive charge to the under surface and repels a negative charge to the upper. The plate is now touched with the finger, and the induced negative electricity being repelled and free, passes off. The plate then retains a bound charge of positive electric ity and, when raised from the cake, the charge distributes itself uniformly over the surface. The charge is sufficient to yield a spark when another conductor is brought near the plate. The plate may then be replaced, touched, and when removed will possess another charge. The original charge on the cake, however, remains substantially the same in amount.

It may appear from the above that there is a gain in energy without a corresponding expenditure of work. This is not the case, however, for every time the plate is raised, the attraction between the unlike charges must be overcome and work is therefore expended in raising the plate.

Electric Machines. The electrophorus is a very elementary form of electric machine, but there are other types which are much more powerful. One type operates upon the same princi-

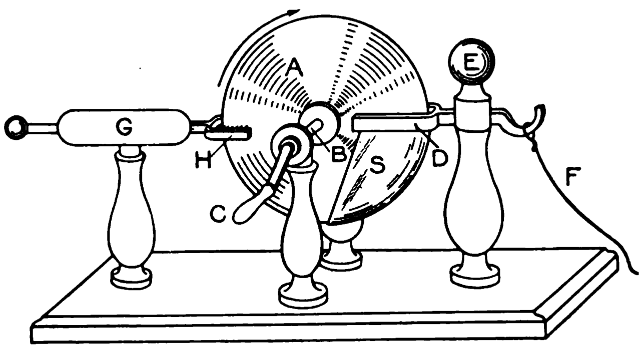


Fig. 13.

ples as the electrophorus; the initial charge induces other charges, which are conveyed by the moving parts of the machine to some other part, where the induced charges may be accumulated. In another type the electricity is produced by friction. Fig. 13 illustrates the plate electric machine which is of the frictional type. The machine consists of a plate, *A*, of glass or ebonite, having its shaft, *B*, provided with a handle, *C*. A pair of rubbers or cushions, *D*, press against opposite sides of the glass and are in electrical connection with the insulated negative conductor *E*. The cushions are usually made of leather and covered with an amalgam of tin, zinc and mercury. The prime conductor *G* is supported by an insulating standard and carries two arms, *H*, which extend one on each side of the plate. These arms carry teeth in the form of combs which extend inwardly, but are not in contact with the plate. Electricity tends to escape from sharp or pointed projections, and round, polished surfaces are best adapted to retain a charge. A silk flap *S* is attached to the cushions and partially covers the plate.

When the handle is turned, the frictional contact causes the rubber to be negatively electrified and the plate positively. The positive charge is carried around on the plate and acts inductively upon the prime conductor *G*, repelling a positive charge to its distant end and attracting a negative charge. The negative electricity, being attracted by the positive charge on the plate, passes readily to it by means of the combs *H*, and these charges are thereby neutralized. Hence that portion of the plate which has passed the combs retains no charge, but an induced, positive charge accumulates on the conductor *G*. Upon passing the cushions, that portion of the plate is recharged, and the action is repeated. The lower half of the plate is therefore always charged, and the other half is neutral. As each successive part of the plate passes the cushion it receives a positive charge, which is neutralized when it passes the combs. The flap *S* is used to reduce electrical leakage from the plate. When positive electricity is to be collected on *G*, conductor *E* is put in connection with the earth by means of a chain or wire, *F*. The negative electricity of the cushions is thereby neutralized. Negative electricity may be collected upon conductor *E*, by connecting *G* to ground instead of conductor *E*.

Condensers. A condenser is an apparatus for accumulating a large quantity of electricity on a comparatively small surface. The form may vary considerably, but in all cases it consists essentially of two conductors separated by a non-conductor, and its action depends upon induction.

In explaining the action of the condenser, the apparatus illustrated in Fig. 14 will be considered. The two plates *A* and *B* are insulated conductors, and *C* is a glass plate between them. Each of the conductors has a pith ball *a* and *b* connected with it. Let plate *A* at first be at such a distance from *B* as to be out of its sphere of influence. The plate *B* is then connected by the conductor x, to the positive conductor of an electrical machine, and receives a positive charge, which is distributed uniformly over its surface. The pith ball or pendulum b will diverge widely, and if connection with the charging machine then be broken, no change in the distribution of the electricity occurs. However, when plate A is placed in the position shown, the distribution is considerably changed. This plate is connected to the earth by a conductor y. The positive charge on B now acts inductively across the intervening space and glass-plate C, repelling a positive charge to the earth through y, and attracting a negative charge which resides on the face n of plate A. This negative charge now reacts upon the positive of plate B and attracts it. The uniform distribution on this plate is then disturbed and the positive electricity accumulates on the face m of plate B. That the density of charge on the other portions of conductor B is diminished, is shown by the fact that pendulum b diverges less. Owing to there being less electricity on portions of B than before, B can be recharged until the pendulum diverges as much as at first. The

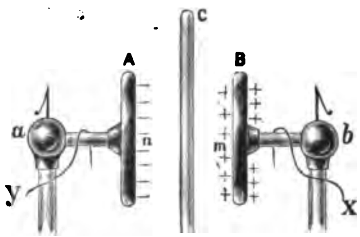
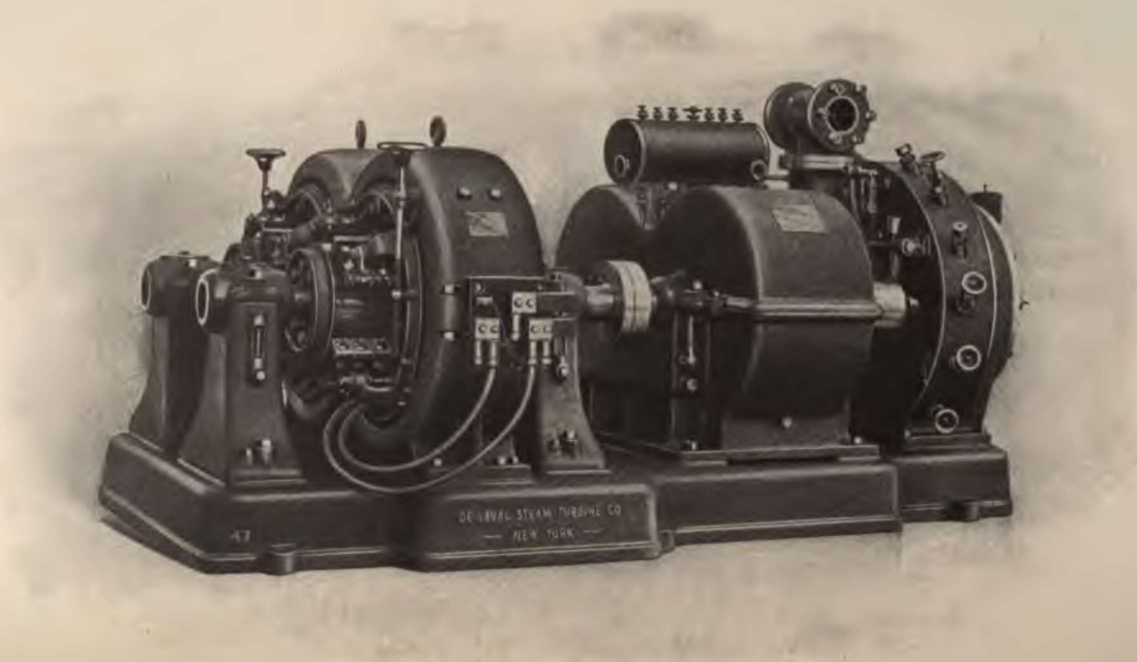


Fig. 14.

effect of plate A, therefore, is to condense the electricity on face m of plate B and thus increase its capacity for more electricity. Electricity is then distributed over the entire surface of B, but is much more dense on face m. If the connections x and y be broken and the plates separated so that they have no effect upon each other, the positive charge will then be distributed equally over the surface of B, and the negative charge equally over surface A. This is shown by the pendulums diverging much more than before.

The nearer the plates A and B are to each other, and the greater their size, the greater the capacity of the apparatus; that is, the greater may be the charge on B.



75 K.W. TURBINE DYNAMO, D.C.

De Laval Steam Turbine Co.

Leyden Jar. The Leyden jar is the most convenient form of condenser. It consists, as shown in Fig. 15, of a glass jar, coated within and without for about two-thirds of its height with tin foil. The stopper has a metallic rod passing through it which communicates with the inner coating by means of a small chain. The upper end of the rod terminates in a knob. The upper portion of the jar, the stopper and the supporting rod are usually coated with shellac to protect them from moisture. The inner coating corresponds to the collecting plate *B* of Fig. 14, the glass to the insulating plate *C* and the outer coating to the condensing plate *A*.

The jar is charged by holding the knob to the prime conductor of an electrical machine or other source of electricity, and connecting the outer coating to the earth by a wire or chain, or by holding the jar in the hand. When the knob is presented to the positive conductor of the machine, positive electricity is accumulated on the inner coating and negative electricity on the outer coating. The positive charge acts inductively through the glass and repels a positive charge to the earth and attracts a negative charge on the inner face of the outer coating. The action of the jar is therefore the same as that of the condenser previously considered.

Fig. 15.

The jar should be made of good glass, should be kept dry and free from dust. The thinner the glass the greater is the capacity, but if the glass is too thin it will not be effective in insulating the charges from each other. In such a case a spark will pass from one coating to the other directly through the glass.

The jar may be discharged by connecting the inner and outer coatings by a conductor. If the outer coating be held in one hand, and the other hand be presented to the knob the person will experience a severe shock, as the arms and body then provide a path for the electricity to unite. To eliminate danger in discharging, a pair of discharging tongs should be used. These consist of jointed brass rods provided with knobs at the separable ends and also provided with insulating handles. One of the knobs is brought in contact with the outer coating and the brought near the knob connected to the inner coating. A bright spark then leaps between these two knobs and the discharge is accomplished.

For the accumulation of powerful charges, a *battery* of jars is used. This consists of several jars, which have all the inner coatings or knobs connected together and all the outer coatings connected together. The battery is charged and discharged in the same manner as a single jar; in fact, the battery is equivalent to a single jar having very large inner and outer coatings. Great care must be taken in charging or discharging a battery, as a shock received may be serious enough to prove fatal.

DYNAMIC ELECTRICITY.

Dynamic electricity, or electrodynamics, considers the flow of electricity in *currents*. In the preceding pages the static charge has been considered, but it has been shown that such a charge may pass readily from one conducting body to another when a suitable path is provided. If electricity could be supplied just as fast as it flowed away, there would be a continuous flow, or current of electricity. Hence if one end of a wire is kept positive and the other negative, electricity constantly flows from one end to the other. This result may be obtained by chemical action, heat or induction. The latter method, which includes the movement of wires across a magnetic field is used in the dynamo and is fully considered in the following discussions. In all cases when a continuous current flows there must be a complete curcuit provided.

Voltaic Cell. A continuous current is obtained from the voltaic cell, and the source of the electricty is the chemical action. Such a cell is illustrated in Fig. 16. The glass jar *A* contains dilute sulphuric acid, in which are placed the copper plate *C* and the zinc plate *Z*. When a wire connects the two plates as shown, a continuous flow of electricity takes place (as indicated by the arrows) from the copper plate through the wire to the zinc plate and through the liquid to the copper plate. The flow of current tends to neutralize the difference in electrical condition of the plates, but the chemical action within the jar maintains this difference. This electrical difference between the plates is called the *potential* difference; and the greater the amount of potential difference, the greater is said to be the *pressure, electromotive force* or *voltage*, which causes a current to flow. The strength of the current passing depends directly upon the amount of this electromotive force. The current strength also depends upon the amount of *resistance* to its flow. If the circuit is short and made up of good conductors, the current will be much stronger than if it were long and made up of poor conductors.

Flow of Electricity. Electricity, although commonly described and referred to as *flowing* through a circuit does not actually *flow*. There is no transfer of matter along the circuit. A wire carrying a current looks the same as one that is not, and that electricity is present is only evident by the heating, chemical or magnetic effects produced. It is convenient, however, to describe electricity as flowing, and this term suffices for all practical purposes.

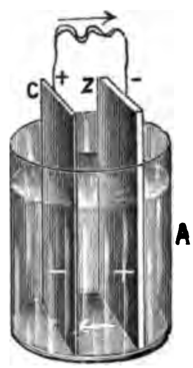


Fig. 16.

In order to show the relation between electromotive force, current and resistance, electricity flowing in a circuit is often compared to the flow of water in a pipe which connects two reservoirs containing water at different levels. When a clear path is provided, the water will flow from the reservoir at the higher level to the one at the lower level, and the greater the difference in the levels the greater is the pressure and consequent flow of water. Also the water will flow much faster through a short large pipe, than through a long and small one. Similarly, the greater the pressure or electromotive force the stronger is the current of electricity, and the greater the resistance of the circuit the less the current. This analogy must not be too closely applied, however, for the reason that with water there is an actual transfer of matter.

Internal and External Resistance. The circuit shown in Fig. 16 may be divided into two parts,—the *internal*, which includes the plates and liquid, and the *external* circuit which consists of the wire connecting the plates. If this wire is small and long, it will have a high resistance and only a weak current will flow. The resistance of liquids as compared with m siderable. The internal resistance of a cell may be reduced by having the plates large and putting them close together. Gases are poor conductors of electricity, and hence the bubbles caused by the chemical action and which cling to the plates, greatly increase the internal resistance.

Fig. 17.

Fig. 18.

Chemical Action in the Cell. The essential elements of a voltaic cell are: a plate, which may be oxidized, such as zinc, a liquid capable of acting on this plate, such as sulphuric acid, and an inactive plate, such as copper. When the wire connecting the plates is broken, there is no current, but upon closing the circuit chemical action takes place and a current flows. The chemical reaction which occurs is represented as follows:

$$Zn + H_2SO_4 = ZnSO_4 + H_2,$$

which is equivalent to saying that the zinc (Zn) combining with the sulphuric acid (H_2SO_4), produces zinc sulphate ($ZnSO_4$) and free hydrogen gas (H_2). The hydrogen is given off as a gas from the liquid and zinc sulphate remains in solution. This action takes place as long as the current flows and depends upon the amount of current flowing. The zinc gradually dissolves into the liquid and the latter gradually becomes a solution of zinc sulphate. When the liquid no longer contains any acid or when the zinc is used up, the chemical action ceases. The spent liquid must then be replaced by a new acid solution and a new piece of zinc substituted.

Polarization. One great objection to the simple voltaic cell is that the current produced, rapidly decreases in strength after the circuit is closed for a short time. This is due mainly to the collection of hydrogen bubbles upon the surface of the copper plate. This coating of bubbles hinders the direct contact of the copper plate with the liquid as its effective area is reduced. This also greatly increases the internal resistance of the battery.

When this accumulation of hydrogen bubbles takes place, the cell is said to be polarized. In order to reduce this action and so enable a cell to maintain a constant current for some time, single fluid cells have been largely replaced by double fluid cells. In these the inactive plate, about which the bubbles would otherwise collect, is placed in a liquid which chemically unites with the hydrogen.

Among the numerous forms of cells now manufactured, the following are described as being among the most important.

Smee's Cell. In this cell, which is illustrated in Fig. 17, polarization is reduced by mechanical means. The cell consists of a silver plate, coated with a deposit of finely divided platinum, and suspended between two zinc plates in dilute sulphuric acid. The middle plate has a roughened surface due to the deposit of platinum, and the hydrogen bubbles therefore readily disengage from its surface and pass off.

Bichromate Cell. This cell, shown in Fig. 18, has the zinc plate suspended between two carbon plates which are joined together at the top. The solution used is made up of dilute sulphuric acid and bichromate of potash. The latter substance chemically unites with the free hydrogen and so prevents polarization. This solution also attacks the zinc, even when the circuit is open, and when not in use the zinc plate is raised above the solution by the rod *A*.

Leclanche Cell. In place of the sulphuric acid solution, this cell is provided with a solution of ammonium chloride (salammoniac), in which a zinc rod is placed. Within the jar containing this solution is placed a porous cup, as shown in Fig. 19. This contains a rod of carbon, which is the inactive element, and closely packed about it is black oxide of manganese and powdered carbon. The oxide slowly gives off oxygen and ts accumulation of hydrogen about the carbon. The porous cup, although it does not interfere with the passage of the current, protects the zinc from the action of the oxide. This cell is much used in connection with telephones and electric bells, or where it is desired to use it for only a few minutes at a time. If used for a long period, the current strength decreases, but quickly regains its original power when the current is interrupted. It is therefore well adapted for intermittent service.

Daniell Cell. The Daniell cell (Fig. 20) is made up of an outer portion of copper, which serves as the inactive element. Within this is a saturated solution of copper sulphate, and crystals

Fig. 19.

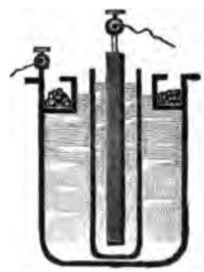


Fig. 20.

of copper sulphate are provided in perforated cups at the top, so that they may dissolve and keep the solution saturated. A porous cup containing dilute sulphuric acid or zinc sulphate and a rod of zinc, completes the cell. The porous cup protects the zinc from the copper sulphate solution, and this solution prevents the hydrogen from accumulating about the copper. The hydrogen unites chemically with the copper sulphate forming sulphuric acid and free copper. The free copper is then deposited upon the outside copper portion. The action is represented as follows:

$$H_2 + CuSO_4 = H_2SO_4 + Cu,$$

which is equivalent to saying that hydrogen united with copper sulphate produces sulphuric acid and copper.

This cell is very constant in its action because, as long as the copper sulphate solution is saturated, no polarization can take place. This cell is much used in telegraphy, and is kept on a closed circuit, the interruption of the circuit being used to give the signals, instead of the closing of the circuit.

Grove Cell. In the Grove cell (Fig. 21) a hollow cylinder of zinc is placed in dilute sulphuric acid. Within this cylinder is a porous cup containing strong nitric acid and a strip of platinum for the inactive element. Polarization is prevented by the hydrogen uniting with the nitric acid. This cell has a low internal resistance and can produce a strong current for several hours.

Bunsen Cell. This is similar to the Grove cell, except that the platinum is replaced by a rod of carbon (Fig. 22). It has a slightly higher electromotive force than the Grove cell and is less expensive, but it has higher internal resistance.

Fig. 21.

Fig. 22.

Gravity Cell. Where one of the two liquids used in a cell is heavier than the other, their difference in specific gravity may be depended upon to keep the liquids separate, instead of using a porous cup. The heavier liquid then remains at the bottom of the cell and the lighter one forms a layer above it. Fig. 23 shows such a cell, which is the same as the Daniell cell except that no porous cup is used. A copper plate at the bottom is surrounded by crystals of copper sulphate and covered with a solution of the same. The zinc is supported above this and in a dilute solution of sulphuric acid or zinc sulphate. The copper sulphate solution being the heavier remains at the bottom and prevents polarization. The two solutions do not remain entirely separated, however, as the heavier solution slowly diffuses upward.

Dry Cell. In this cell, which is more properly called a *moist* cell, the usual liquid solutions are dispensed with, and in place of them the cell is provided with substances c aining

Electromagnets may be made very powerful, and when made in the form of a horseshoe have great lifting power. A horseshoe electromagnet is shown in Fig. 27. The winding of the two coils *A* and *B* must be such that the ends of the horseshoe have opposite polarity. This condition is fulfilled if the winding

Fig. 26.

on the two links is in the same direction, when the horseshoe is straightened out.

Applications of Electromagnets. The great advantage in using the electromagnet lies in the control of its magnetism. When the current is passing, the core is strongly magnetized, and when no current flows it ceases to act as a magnet. Hence its action may be controlled by simply opening or closing the circuit by a key or switch, the source of the electricity being included in the circuit. This control of the magnet may be accomplished at great distances by merely extending the wires from the coil to the distant point and operating the switch or key at that point.

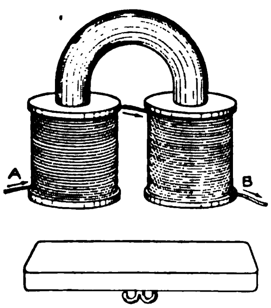


Fig. 27.

Telegraphic instruments are constructed upon this principle, the closing of a key at a distant point causing the electromagnet to attract a piece of iron called its armature, supported near its poles, and so give a signal. When the current ceases to flow, the armature is forced away from the poles by the action of a spring, the force of the spring being overcome, however, whenever the current passes.

The electromagnet is also used in electric bells. The armature carries a hammer which strikes against the bell whenever the armature is attracted. By the rapid opening and closing of the circuit, which is accomplished automatically, the hammer is made to strike the bell repeatedly. Electric clocks are also governed by the action of electromagnets.

PRODUCTION OF CURRENTS BY INDUCTION.

We have seen that magnets may induce magnetism in pieces of soft iron and attract them. We have also seen that electric charges may induce charges in other bodies. Induced *currents* may be produced by the relative movement of a magnetic field and a neighboring conductor, or by the action of a current in one conductor upon a neighboring conductor. The production of

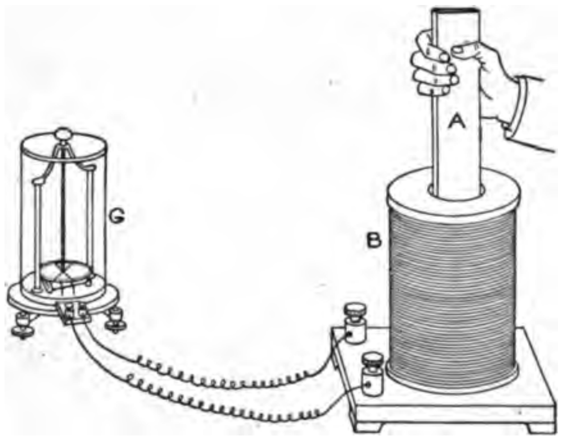


Fig. 28.

induced currents is therefore a very different phenomenon from that of induced static charges.

Induction by Magnets. Fig. 28 represents a coil *B*, having connected in its circuit an instrument *G* for the purpose of indicating the presence of any current. The magnet *A* is adapted to be thrust within the coil. Upon forcing the magnet rapidly within the coil, the instrument will show that a momentary current passes. The current continues as long as the magnet is in motion, and ceases as soon as the magnet is brought to rest. The quicker the magnet moves the greater is the strength of the induced current. Upon withdrawing the magnet a current is also induced, and this flows in the opposite direction to the former current.

These induced currents are caused by the field surrounding the magnet moving or cutting across the wires composing the coil. If a current were passed through the coil, it would create a magnetic field, so on the other hand, the movement of a magnetic field within the coil produces a current. It makes no difference whether the magnet or the coil is moved, so long as there is relative movement. This production of a current by the relative movement of a magnetic field and a conductor, is the fundamental principle of all dynamos.

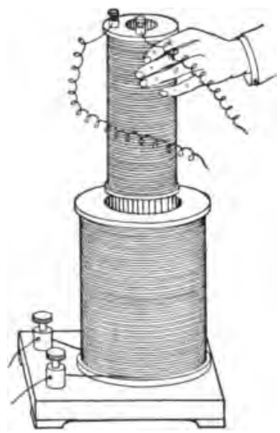


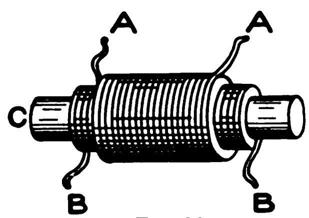
Fig. 29.

Induction by Currents. As a solenoid is surrounded by a magnetic field similar to that of a bar magnet, it follows that if a solenoid carrying a current were thrust within another coil, induced currents would be produced in the latter. This experiment is illustrated in Fig. 29. These induced currents, as in the case when the magnet is used, only flow during the motion of the solenoid. When the solenoid is inserted, the induced current flows in one direction and when withdrawn, it flows in the opposite direction. The insertion of the solenoid induces a current which has a direction opposite to that in the solenoid, and the withdrawal induces a current which has the same direction as that in the solenoid.

Induction Coil. Suppose now that the two coils shown in Fig. 29 are placed one within the other, there being no current passing, and that a current is afterwards passed through the inner coil. Upon permitting the passage of a current in the inner coil a momentary current is induced in the outer coil, the same as if a magnet had been thrust into the coil. This induced current continues, however, only while the current in the inner coil is increasing in value from zero to its normal amount. As soon as this normal strength is reached the induced current ceases to flow. Now when the circuit of the inner coil is broken and its current ceases to flow, another momentary current is induced in the outer coil, which has a direction opposite to that formerly passed through it. Such an instrument for producing induced currents is called an *induction coil.* The coil through which the original current is passed is called the *primary* coil, and that in which the currents are induced is called the *secondary* coil. The induction coil is the fundamental principle of transformers, commonly used in long distance power transmission.

Fig. 30 illustrates an induction coil having the two sets of windings *A* and *B* and also supplied with a soft iron core *C.* This iron core greatly increases the amount of induction.

The production of induced currents by opening and closing, or making and breaking the primary circuit, is similar in action to thrusting a magnet within and withdrawing it from a coil. When a magnet is used, the induction is caused by the magnetic



A is secondary coil.
B is primary coil.

Fig. 30.

field moving across the wire composing the coil. Now when the primary circuit is closed, a magnetic field is created, which is equivalent to thrusting a magnet within the coil. The breaking of the primary circuit is equivalent to withdrawing the magnet, and so induces a current. The current induced by closing the primary circuit is *opposite* in direction to that of the primary current, and that induced by breaking the primary circuit is in the *same* direction as the primary current. The induced currents are only caused by the changing in strength of the magnetic field surrounding the secondary circuit. Therefore, while a constant current is passing in the primary circuit, there will be no induced currents. When the strength of the primary current changes, however, secondary currents will be induced. The strength of these induced currents will depend upon the abruptness of change in the primary current, and their direction will depend upon whether the primary current increases or decreases.

It should be remembered that before a current can flow there must be a closed circuit, and an electromotive force. A current flows in the secondary circuit only when it is closed, but the electromotive force exists whether or not the secondary circuit is closed. Strictly speaking the electromotive force is first produced or generated, and the current then flows when the circuit is closed. The value of the electromotive force generated in the secondary, depends upon the number of turns in the same; a much higher electromotive force being generated in a coil of a large number of turns than in a coil of a few turns. This fact is of great practical importance, for it thus provides a means of obtaining very high electromotive forces.

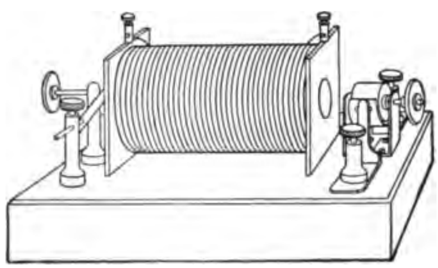


Fig. 31.

Fig. 31 illustrates an induction coil arranged to generate a very high electromotive force, and for producing sparks between widely separated points. The primary coil consists of a few turns of coarse wire, and about this is the secondary coil made up of many thousand turns of fine wire, all of which are well insulated. In the primary circuit are connected a few Grove's or Bunsen's cells and a switch for interrupting the circuit. The making and breaking of the primary circuit generates a very high electromotive force in the secondary. Sparks of considerable length may be produced between the terminals of the secondary by this type of coil. A condenser is used in connection with the device, in order to decrease the electromotive force induced by closing the primary circuit, and to increase that induced by opening the primary circuit. The sparking therefore occurs at the breaking of the primary circuit. A powerful induction coil made at London, in which the secondary coil contained 280 miles of wire wound in 340,000 turns, yields a spark $42\frac{1}{2}$ inches in length, when worked by 30 Grove's cells.

Mutual and Self-Induction. Induction produced in one conductor by currents in another, which has no electrical connection with the first, is called *mutual* induction. We have seen that mutual induction is caused by the change in strength of the magnetic field surrounding the secondary coil. The primary coil must necessarily be subject to the same change in field strength, which is therefore acted upon inductively as well as the secondary coil. This reaction tends to oppose any increase or decrease in the primary current. It is greater for a coil having a large number of turns or one provided with an iron core. This inductive action of a coil upon itself is called *self-induction*. Electromagnets have very high self-induction. Upon closing the circuit in such a coil its self-induction causes the current to increase in strength very slowly, and upon opening the circuit self-induction tends to prolong the current, and produces what is termed an "extra current." The high electromotive force causing this extra current, may be sufficient to give a dangerous shock, and produces a bright spark where the circuit is opened.

HEATING EFFECTS OF CURRENT.

Heating Depends upon Resistance. We have seen that some substances are very good conductors of electricity, that others are fairly good and that others are very poor conductors. That is, some substances offer very much more resistance to the flow of electricity than others. In order to force the current through this resistance, a certain amount of energy must be expended and the greater the resistance, the greater is the amount of energy required. The energy which is thus consumed, appears in the form of heat. From every part of a circuit through which a current is flowing, heat is dissipated, and this heating raises the temperature of the circuit a certain amount. A short, stout copper wire has low resistance, and so causes but little heat to be generated. Also on account of its large radiating surface, this heat is readily given off to the surrounding air, and therefore its temperature is raised only to a small extent. A fine platinum wire, however, has high resistance and but small radiating surface, hence if the same current be passed through this wire, it will come to a high temperature and may even become incandescent.

The laws of heating in electrical circuits were first formulated by Joule. Joule's law is as follows:

The number of heat units developed in a conductor is propor-

tional to its resistance, to the square of the current, and to the time that the current lasts.

The amount of heat developed therefore increases in direct proportion to the resistance, but increases as the ***square*** of the current. Hence doubling the resistance, doubles the heat generated, if the current remains the same, but doubling the current increases the generation of heat four fold with the same resistance.

Applications. The heating of a wire carrying a current is made use of for lighting purposes, and again for blasting, exploding sub-marine mines, etc. Conducting wires are run from the explosive material to a distant point, and include a battery and

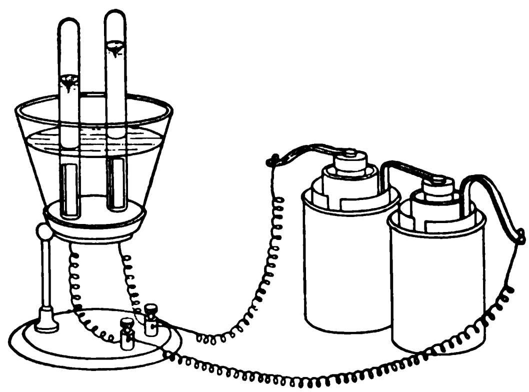


Fig. 32.

piece of fine platinum wire in the circuit. Some combustible substance is placed around the platinum, and serves to ignite the main charge when the platinum wire is heated. Upon closing the circuit this wire becomes hot and the explosion takes place.

This principle of heating is also applied to ***fuses***, used for the protection of electric lighting or power circuits. The fuse consists of an easily fusible metal which is inserted in the circuit. The passage of an excessive or dangerously large current heats the fuse to its melting point and so breaks the circuit. The cause of the large current may then be removed and a new fuse inserted in place of the old one.

Electric welding is accomplished by passing a powerful cur-

THE MORTON-WIMSHURST-HOLTZ INFLUENCE MACHINE

This machine illustrates one of the commercial applications of the static machine described on page 16. It is intended for X-ray purposes and therapeutical use, for which it has many advantages over the induction coil, which is sometimes substituted for it, being entirely self-contained and independent of outside sources of power. These machines vary in size from 6 revolving and 6 stationary 28-inch plates to 12 revolving and 12 stationary 32-inch plates. The spark is from 9 to 15 inches in length.

rent through two rods held together. The heating at the junction softens the metal and the rods become welded.

The electrical heating of cars and of cooking utensils is accomplished by passing a current through wires of high resistance.

Thermo-Electric Currents. If the junction of two dissimilar metals forming part of a circuit, is heated, a current is produced. If a piece of bismuth and a piece of antimony be soldered together and form part of a circuit, then if the junction be heated to a temperature higher than that of the rest of the circuit, a current will flow in the direction from bismuth to antimony through the heated section. If the junction be cooled below the temperature of the rest of the circuit, a current will flow in the opposite direction. The current will continue to flow as long as the difference in temperature is maintained. Currents thus produced are called *thermo-electric* currents. This phenomenon is commonly known as the Seebeck effect from the name of its discoverer.

About the only application of the above phenomenon is made to instruments for detecting very slight differences in temperature. These are arranged so that a very small rise in temperature of a bismuth and antimony junction, will generate a current which may be measured by a sensitive instrument in the circuit. Other metals may be used but the effect is not nearly so pronounced.

CHEMICAL EFFECTS OF CURRENTS.

Electrolysis. When a current of electricity is passed through water from one terminal of a circuit to the other, the water is decomposed into its constituent parts, hydrogen and oxygen. The hydrogen gas rises in bubbles from one terminal and the oxygen gas from the other. Fig. 32 illustrates an arrangement of apparatus by which this decomposition may be attained, and by which the gases may be separately collected. The current from a couple of cells is conducted through one wire to a vessel containing water, then through the liquid and through the other wire to the cells. Pure water is a poor conductor, and a few drops of sulphuric or hydrochloric acid are added to increase its conductivity. The two terminals project through the bottom of the vessel and over each of them is placed a tube 'e upper end and filled with water. The gas given off from each terminal rises and collects in the upper portion of the tubes. Oxygen rises from the terminal by which the current enters the liquid and hydrogen from the terminal by which it leaves. Oxygen is therefore collected in one tube and hydrogen in the other. Two volumes of hydrogen and one volume of oxygen unite to form water, and hence in its decomposition the volume of hydrogen collected is twice that of the oxygen.

Other liquids may be decomposed by passing a current through them, and this process of decomposition is called *electrolysis*. Liquids which may be decomposed in this manner are called *electrolytes*. The terminals by which the current enters and leaves the liquid are called *electrodes*. The *anode* is that terminal by which the current enters and the *kathode* is that by which it leaves the liquid.

Some liquids such as oil, which is an insulator, and mercury which is itself an element, cannot be decomposed by an electric current. Dilute acids however, and solutions of metallic salts are readily decomposed.

For an example of the decomposition of a salt we will take a solution of copper sulphate for the electrolyte. The current from a single cell is sufficient to decompose this salt. By passing the current through the liquid, metallic copper is separated from its compound and is deposited in a pure state upon the kathode. The remainder of the compound unites with the water to form sulphuric acid and oxygen. The latter rises in bubbles from the anode. The final result therefore, is that the kathode receives a coating of pure copper and the liquid becomes dilute sulphuric acid. If the anode consists of copper, it will dissolve into the liquid forming copper sulphate as fast as the pure copper is deposited upon the kathode. In this case the action of the current is to transfer the copper from the anode to the kathode.

The amount of chemical action in an electrolytic cell depends upon the strength of current, and the time it continues.

Electrotyping. The decomposition of salts by the electric current has received a most important application in *electrometallurgy*. By this process exact reproductions may be made of type, plaster casts, medals, etc. In the usual process a wax mould of the object is first made, and this is coated with graphite or powdered bronze to render it a good conductor. The mould is then suspended in, and forms the kathode of an electrolytic cell. For the formation of a copper electrotype, the anode is a plate of copper and the electrolyte is copper sulphate. The passage of the current produces an exact reproduction of the original object on the wax mould. Even the faintest lines are accurately reproduced.

Electroplating. By this process the cheaper metals may receive a thin coating of gold, silver, nickel, etc. The objects to be plated are suspended in the electrolytic cell and form the kathode. In electro-gilding the electrolyte is a solution of double cyanide of gold and potassium, and a plate of gold forms the anode. This plate dissolves into the liquid as fast as the gold coating is deposited upon the objects to be coated. For electro-silvering a double cyanide of silver and potassium and a plate of silver are used. Iron objects are usually coated with a copper deposit before being gilded, silvered or nickeled. The copper presents a better surface for the other metals and gives more durable results.

Accumulators, also called storage or secondary batteries, consist of cells which are capable of giving out electrical energy, in virtue of the chemical change caused by first passing a current through them from an external source.

The simplest type of accumulator is called the Planté battery from the name of its inventor. This cell consists simply of lead plates in dilute sulphuric acid. The plates are "formed" or made active by repeatedly "charging" and "discharging" the cells. That is, a current from an outside source is passed through the cell from one plate to the other, and then by connecting the plates by a wire a current will flow until the potential of each plate is the same. By repeated charging and discharging, the capacity of the cell is greatly increased. No electricity is stored up by the plates as with the Leyden jar, but the effect is due entirely to a chemical change on the surface of the plates. By repeated chargings this chemical change penetrates deeper and deeper into the plates and thus increases their capacity. The current received from the cell flows in an opposite direction to that by which the cell is charged.

THE TELEGRAPH.

Having considered the electromagnet and the effect produced in a core of soft iron, by a current of electricity which passes through a coil of insulated wire surrounding it, we are prepared to apply these principles to the electric telegraph.

Various devices have been tried, with more or less success, for transmitting and recording signals from one point to another.

The apparatus used in one of these early attempts caused sparks from Leyden jars to pass through a circuit. Another was operated by means of a galvanometer needle which was deflected to the right or left.

None of these attempts were of any practical value except that they served to lead up to the telegraph of the present day. There are now two successful methods of operating telegraph lines; namely the "Open Circuit" and the "Closed Circuit" systems. The former is used in Europe and its chief advantage is that no energy is consumed from the batteries except when signals are actually being transmitted. The latter system which is used almost entirely in America, has on the other hand, advantages which offset this. On account of its greater importance in this country we will consider more in detail the "Closed Circuit" system.

In its simplest form this system consists of three principal parts connected in series in the circuit:

1. A key for transmitting the signals.
2. An instrument for receiving these signals.
3. A battery which furnishes the current to operate it.

The Morse Sounder. The instrument most commonly used for receiving the signals is the Morse sounder, shown in Fig. 33. It consists essentially of an inverted electromagnet E of the horseshoe type. This electromagnet differs somewhat from the one shown in Fig. 27, in that it is made up of two cores and a yoke or back strap B in order to furnish a better bearing for the electromagnet upon its base than would be possible with one having a rounding back. Above the poles of this magnet, an armature A of soft iron is attached to a pivoted lever L of non-magnetic material, which is controlled by a spring S. When a current passes through the coils of this electromagnet, the cores become magnetized and attract the armature downward. Just before it touches the poles of the electromagnet however, the lever to which it is attached, strikes a metallic stop F and a click is heard. When the current ceases to flow, the cores of the electromagnet

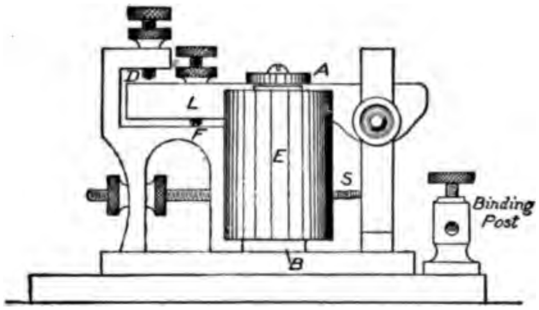


Fig. 33.

lose their attractive force. The armature is then carried upward by means of the spring which acts on the lever to which the armature is attached. The lever then strikes against another stop D and another click is heard. The range of stroke or play of the lever is adjusted by set screws.

AMERICAN MORSE CODE.

A . —	J — . — .	S . . .	2 . . — . .
B — . . .	K — . —	T —	3 . . . — .
C . . .	L ——	U . . —	4 . . . . —
D — . .	M — —	V . . . —	5 — — —
E .	N — .	W . — —	6 . . . . . .
F . — .	O . .	X . — . .	7 — — . .
G — — .	P	Y	8 — . . . .
H	Q . . — . .	Z	9 — . . —
I . .	R . . .	1 . — — .	0 ————

If the duration of time of current flow is very short, the interval of time between these two clicks will be correspondingly short. The signal in this case would be a "dot." If the interval between the two clicks be longer, the signal would be a dash.

In this manner by a telegraphic code, consisting of different signals made up of dots, spaces and dashes for all the letters of the alphebet and numbers, it is possible to send and receive messages. Beside the "Sounder" described above in which the receiving operator depends entirely upon sound for the message, there are also in use the "Embosser" and the "Ink Writer."

In the first a sharp point attached to the armature lever cuts the dots or dashes in a strip of paper moved past it by clock work; in the second the dots and dashes are recorded on the moving paper by an inked wheel. These last two methods are, however, little used by expert operators.

The Morse Key. The Morse Key or instrument by which the signals are controlled is shown in Fig. 34.

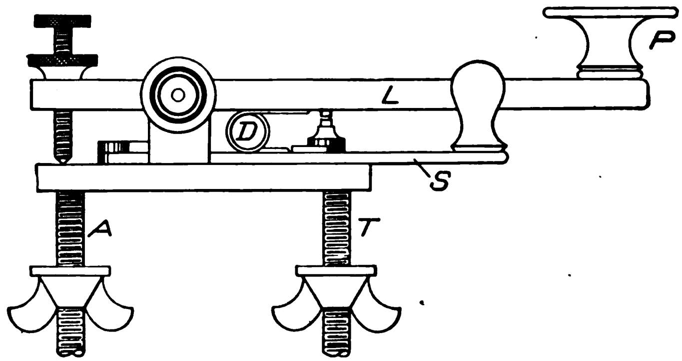


Fig. 34.

It is composed of a pivoted lever L fitted at one end with a circular plate P on which the fingers of the operator rest. The key is secured to the base by two thumb screws A and T, to which the terminals of the circuit are attached. The screw A is in electrical connection with the main body of the key, including the lever. The screw T is insulated from the rest of the key by some non-conducting material, and terminates in a platinum point.

On the under side of the lever and immediately above this point is another platinum tip which, when the lever is pressed down, makes contact, thus completing the circuit through the key.

The lever is kept in proper position when not in use, by a spring D and the length of its stroke is controlled by an adjustable set screw. A switch S, for closing the circuit when the instrument is not in use, completes this piece of apparatus.

The Battery. The battery used for operating the circuit is either the Daniell cell shown in Fig. 20 or the Gravity cell shown in Fig. 23. In the "Closed Circuit" system the batteries are required to furnish current nearly all the time and these cells are remarkably well adapted for this purpose as they do not polarize and require very little attention other than keeping them supplied with copper sulphate and removing the zinc sulphate.

The number of cells used depends upon the length of the line and resistance of the instruments in the circuit.

In actual practice there is a key and sounder at every station on the line, all being connected in series together with a sufficient number of cells to furnish the current. The switches of all the keys being closed, a current will flow through the electromagnets of all the sounders.

When an operator wishes to communicate with a certain station, he opens the switch of his key, thus breaking the circuit and he can then by means of the lever, call the station and send any message he desires over the line. This message will, of course be simultaneously signalled by all the sounders on the circuit.

When the operator finishes his message he closes the switch and is then prepared to receive the reply.

The Relay. In the case of long lines having many instruments in series, the main current would not be strong enough to properly operate the receiving sounder directly, and the relay is then resorted to.

This instrument consists of a horizontal electromagnet, having a large number of turns in its coils, in series with the main line. It has an armature somewhat like that of the sounder already described. It is however more delicately balanced so that less magnetic force is required to attract it.

When the line current flows through the relay, this armature is drawn against its stop, and thus it makes contact for a local circuit including a Morse sounder and sufficient batteries to work it.

In this manner, the main or line current, although not strong enough to operate the sounder directly, can be made to control the sounder in the local circuit, by means of the relay, the armature of which plays the same part in the local circuit as does the key in the main circuit when manipulated by the operator.

THE TELEPHONE.

The modern telephone was invented in 1876 by Alexander Graham Bell and Elisha Gray. Up to this time, many attempts to perfect a successful speaking apparatus had been made but they were all failures. One cause of lack of success was the fact that the inventors had little or no knowledge of acoustics.

In order to understand the operation of the telephone, it is necessary, first of all, to understand the principles underlying the production of sound, or of acoustics. Sound is produced by vibrations in the air set up by whatever may be the cause producing the sound. These vibrations strike the eardrum, and the sensation of sound is conveyed to the brain. The pitch depends upon the rapidity of the vibration, the loudness upon the amplitude, and the quality upon the form of the vibration.

The simplest sort of vibration is that set up by a musical tone, and to give an idea of the rapidity of vibrations for a specific case it may be stated that the musical tone known as middle C is set up by 256 vibrations per second. The vibrations set up by the

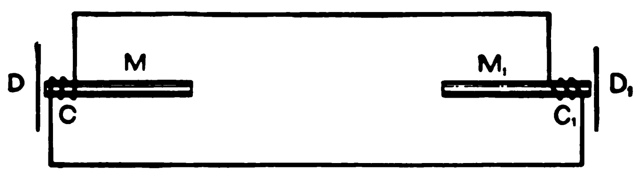


Fig. 35.

voice in speaking are of a much more complex nature in every way, and on this account the earliest telephones could reproduce musical tones, but could not transmit speech.

The earlier telephones served to transmit and reproduce the vibrations of the voice by means of electromagnetic induction. A typical telephone circuit in its simplest form is shown in Fig. 35. There are two similar instruments, one at each end of the circuit; we may consider one the transmitter and the other the receiver. M and M_1 are two permanent bar magnets on the ends of which are coils of fine insulated wire, C and C_1. In front of the magnets are thin elastic disks of sheet iron, D and D_1, commonly known as the diaphragms. Let us consider the left-hand instrument the transmitter, and the other the receiver. The permanent magnet M sets up a certain number of magnetic lines of force through the coil C, and as the diaphragm D offers a path of lower magnetic resistance than the air, many of these lines pass through it. When we speak close to the diaphragm D, the air vibrations cause the diaphragm to vibrate. As it approaches the magnet M more magnetic lines pass through the diaphragm, and when it recedes fewer lines pass through it. This action alters the number of magnetic lines which pass through the coil C, and hence alternating currents are induced in it which are proportional in strength to the rate of change of the number of lines.

These currents also pass through the coil C_1 at the receiving end of the line, and according to the direction in which they flow around the magnet M_1, alternately add to or tend to neutralize its strength. When the current strengthens the magnet, it causes it to attract its diaphragm D_1, and when the current decreases the strength of the magnet, the diaphragm moves away. In this manner the diaphragm at the receiving end is made to vibrate in exact

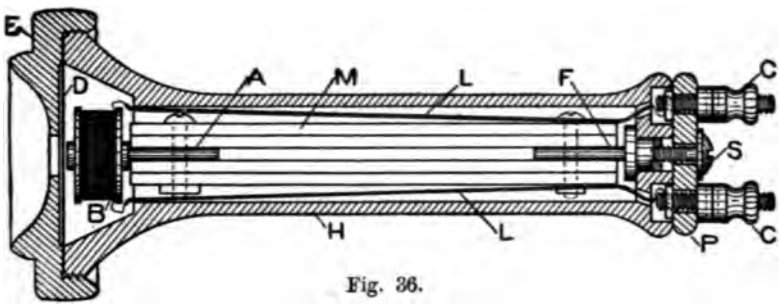


Fig. 36.

unison with the one at the transmitting end, and thus similar vibrations of the air are set up, reproducing the sounds spoken into the transmitter.

The above arrangement has been somewhat modified in the telephone of the present day, and it has been found more convenient to have a separate transmitter at each end of the circuit. The transmitters now in use operate [illegible] different principles, but the receiver is essentially

Receivers. There are two common forms of receiver: the single-pole and the bipolar type.

A single-pole receiver of the Bell type is shown in section in Fig. 36. It consists of a hard rubber case H, in which is placed the laminated or compound bar magnet of steel M. This magnet is composed of two sets of bars separately magnetized; clamped between them by means of screws is the pole piece of soft iron A at one end and the block F at the other end. Upon the pole piece is placed a coil of fine insulated copper wire B; connection being made from it to the binding posts C C by means of heavy wires L L. The binding posts are attached to the end piece P, which is held in place by the screw S which threads into the block F, and thus serves also to keep the magnet in position. The cap E screws to the case and supports the diaphragm D, which is a flexible disk of soft iron. The diaphragm is placed a short distance in front of the pole piece of the magnet, and the portion directly opposite it is free to vibrate.

This instrument is being supplanted to a great extent by the bipolar receiver, which differs from the single-pole receiver in that the permanent magnet, instead of being straight, is constructed upon the horse-shoe principle. This brings both poles in position to act on the diaphragm, giving increased strength of field, and consequently making the instrument more efficient. A soft-iron pole piece is secured to each end of the magnet, and a coil of insulated copper wire is mounted on each pole piece.

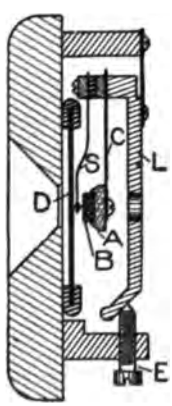


Fig. 37.

At the present time the single-pole receiver is sometimes used for local work, while the bipolar receiver is employed both for this and for long-distance work. There is also another form of receiver known as the watch-case type, which is used to some extent for desk sets and at the exchange switch-board.

Transmitters. The type of telephone just described was originally used as the transmitter as well as the receiver, and for short distances, in which the line resistance was small, gave fairly good results.

It is now the practice to use this instrument as the receiver only, and to use a different form of instrument, together with a battery, for the transmitter. The action of this transmitter depends upon the fact, that if the resistance of a circuit is increased, the current will be decreased, and if the resistance is decreased, the current will be increased. This variation in resistance is produced by varying the pressure between one or more carbon contacts. If the pressure is increased, the resistance is decreased, and if the pressure is decreased, the resistance is increased.

There are three types of transmitter: in the first but one carbon contact is used for varying the resistance, in the second several contacts are used, and in the third granular carbon is employed, thus giving a very large number of contacts.

The Blake transmitter, a section of which is shown in Fig. 37, is an example of the first type. This instrument, in common with all other transmitters, has a diaphragm D somewhat similar to that of the receiver. This is supported in a rubber ring, and is held in place by two damping springs not shown in the cut. Mounted upon a light spring S, and resting against the back of the center of this diaphragm, is the front electrode, which is a platinum pin. Directly back of this piece of platinum, a carbon button B, which forms the other electrode, is supported by means of a spring C, so adjusted that the carbon button bears lightly against the platinum pin. The tendency of the spring S is to press the platinum pin away from the diaphragm; but this is overcome by the stiffer spring C which bears in the opposite direction, and so keeps the platinum in contact with the diaphragm. The electrode B is mounted in a comparatively heavy socket of brass A. Both electrodes can move freely with the vibrations of the diaphragm; but the carbon, on account of the inertia due to the weight of the brass socket, moves more slowly than the other. Any vibration of the diaphragm will, therefore, result in a variation of the pressure between the two electrodes, and thus vary the resistance of the contact.

The two springs S and C are insulated from each other, and the current goes to the contact point by means of one spring and leaves by the other. The adjustment of the pressure is effected by means of the screw E, which bears against the lever L.

This transmitter is quite satisfactory for lines of mo' length, and is used to some extent at the present time. It is, however, somewhat difficult to keep in adjustment, and is not well adapted for long-distance work.

The second type of transmitter mentioned is not much used in this country, and a description need not be given.

The most common form of transmitter, and the one which is rapidly replacing all others, is the Hunnings or granular carbon type. This, as originally planned by its inventor, consists of two insulated plates of conducting material which forms the electrodes of the transmitter, the space between them being filled with granular carbon. The general form of this instrument is shown in Fig. 38. D is the diaphragm of metal or carbon which is clamped between the body of the case C and the cap A by means of screws. Another conducting plate B, of metal or carbon, is placed in the back of the case, and the space between D and B is filled with granular carbon. The conducting plates D and B form the electrodes or terminals of this transmitter. When the diaphragm is spoken against, it of course vibrates, and thus varies the pressure upon the numerous contact points of the granular carbon through which the current must flow to pass from one electrode to the other, and thus the resistance is varied as in the Blake instrument. Larger currents can be used with the Hunnings type of transmitter than with other sorts, and it has the further advantage of allowing a greater variation of resistance.

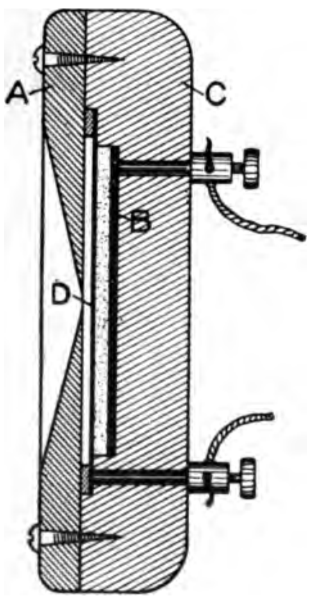


Fig. 38.

The transmitter which is used almost entirely at the present time is known as the "solid back," being a modification of the Hunnings type just described. The case, which is of metal and hollowed out to contain the working parts of the instrument, is enclosed by a brass cover, which also carries the mouth piece. The metal diaphragm is supported in a ring of soft rubber attached to the back of the cover. The electrodes are enclosed in a metal chamber which is lined with insulating material. This electrode chamber is secured by means of a set screw to a metal bridge which is attached to the back of the cover by means of screws. Both electrodes are of carbon, being in the form of discs somewhat smaller in diameter than the containing chamber. The space between the electrodes is filled with granular carbon as is also the space between the circumference of the discs and the insulated walls of the chamber. The rear electrode is mounted upon a brass disc which is screwed to the back of the chamber, thereby holding the electrode securely in place. This electrode being in metallic connection with the containing chamber, is in electrical connection, through the bridge and cover, with the frame of the transmitter which thus becomes one of the terminals.

The front electrode is also backed by a brass disc which is attached to the metal diaphragm of the transmitter by means of a stud which passes first through a mica washer that serves to enclose the electrode chamber, and then through the center of the diaphragm. This stud is fitted with two threads, upon one of which is screwed a nut which clamps the mica washer to the electrode, and upon the other two nuts which clamp the electrode to the diaphragm. A brass collar, which screws to the periphery of the electrode chamber, binds the mica washer securely against it. Connection is made to the front electrode, which is the second terminal, by means of a fine wire brought out to a binding post mounted upon an insulated block.

The vibrations of the diaphragm are communicated directly to the front electrode, which thus varies the pressure upon the mass of granular carbon and consequently serves to vary the resistance. Two damping springs rest against the diaphragm, thus keeping the amplitude of its vibrations within reasonable limits, and checking them as soon as they have performed their part, leaving the diaphragm ready to obey the impulses due to the succeeding sound waves.

This transmitter operates in a very satisfactory manner; excellent contact is made between the carbon electrodes and the particles of granular carbon. Packing of the granules is prevented on account of the space between the periphery of the electrodes and the inner circumference of the chamber, which contains granules that do not become heated by the passage of the current. Hence when the granules between the electrodes become heated they can expand into this portion.

The transmitters of this type manufactured by different companies vary slightly in minor details of construction, but all operate upon practically the same principles.

Simple Telephone Circuit. The earliest form of telephone circuit consisted simply of two Bell receivers connected in series. The one which was being used as a transmitter served as a very small generator which sent alternating currents over the line, and these acted upon the instrument at the other end of the circuit, which was, for the time being, used as a receiver.

After the invention of the carbon transmitter the circuit consisted of a transmitter and receiver at each end of the line, together with the batteries which furnished the power, all connected in series. This arrangement did not give satisfactory results for many reasons, but the use of the induction coil overcame the difficulties previously met with.

A typical circuit with the induction coil is shown in Fig. 39. Here T is the transmitter, B the battery, P the primary and S the secondary of the induction coil, and R the receiver. The primary

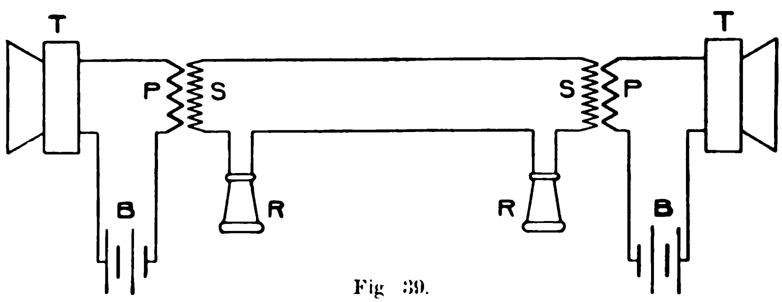


Fig. 39.

circuit contains the transmitter, batteries, and primary of the induction coil, while the secondary circuit contains the receiver and secondary coil. When the transmitter at one end of the line is spoken into, the resistance of the primary circuit is varied, and this in turn varies the strength of the current passing through the primary of the induction coil. Consequently alternating currents are induced in the secondary coil which pass over the line and act upon the receiver at the opposite end.

The action of the induction coil has already been described. The coil used in telephone work has a core made of soft iron wires. Upon this is wound the primary coil, consisting of a comparatively small number of turns of coarse insulated copper wire, and outside of this, and carefully insulated from it, is the secondary coil in which are a great many turns of fine insulated copper wire. Without the induction coil, it is probable that the long distance telephone in its present state of perfection would have been impossible. Its use allows the resistance of the circuit in which the transmitter acts to be very small; with the result that the effects of the variations in resistance due to the transmitter are comparatively large. This low resistance also permits a larger current to flow with a given number of cells of battery. The electromotive force of the secondary current is high, thus being well adapted to overcome the high resistance of the receivers, secondary coils, and line wires. Still another advantage lies in the fact that if the transmitter were connected directly in the main circuit, its effect would be to cause the current in the line to vary in strength but not to change in direction. In other words, the current would be undulating but not alternating. However, better results are obtained if the current which actuates the receiver be an alternating one, and this is of course the nature of the current in the secondary of the induction coil.

Batteries. In telephone work the batteries are required to furnish current for only short periods of time, and the Leclanche cell is admirably adapted for the purpose. It requires very little attention and will furnish a comparatively large current for a short time. Moreover, although these batteries polarize in a short time if kept on a closed circuit, they recover very quickly when the circuit is opened.

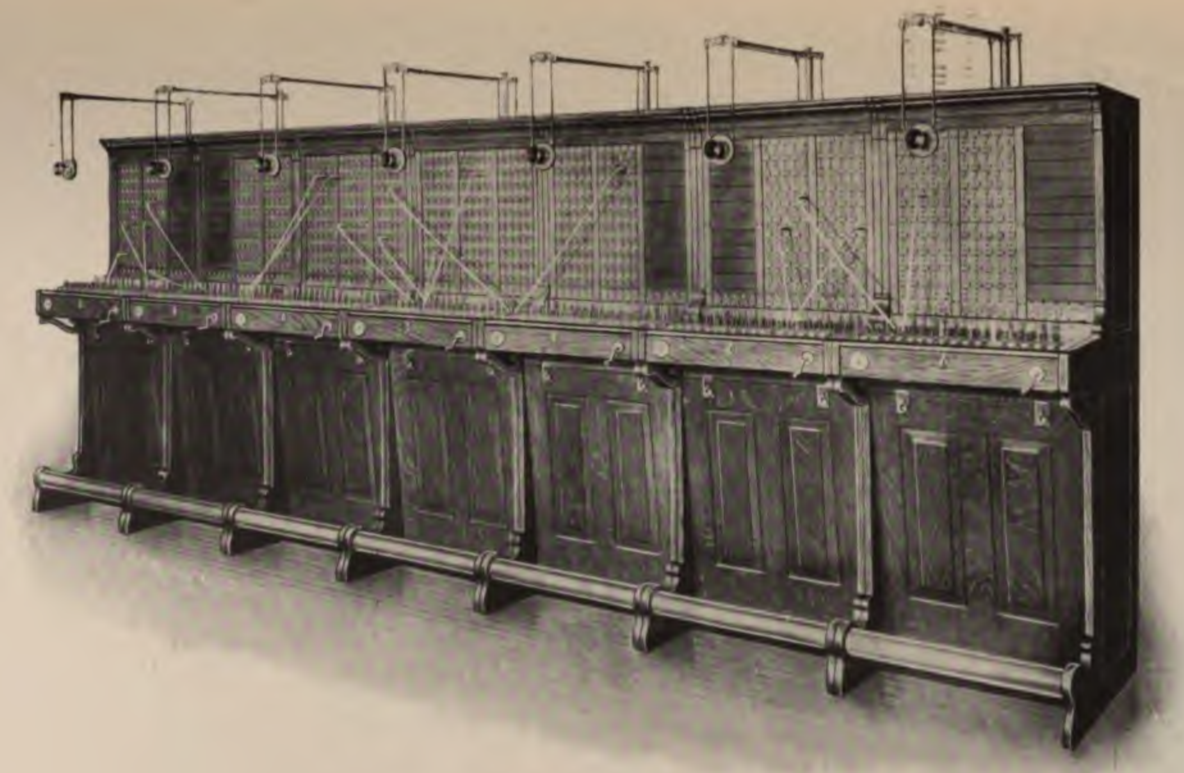
The Fuller cell is also used to a considerable extent. In this cell the plates are zinc and carbon; dilute sulphuric acid is the excitant, and either bichromate of sodium or bichromate of potassium may be used as the depolarizer. The zinc is placed in a porous cup, in the bottom of which is a small quantity of which serves to amalgamate the surface of the zinc and thus prevent local action between the zinc and the impurities which it contains. This cup is then filled with a solution of sodium chloride (or common salt) dissolved in water. In the battery jar is the solution of dilute sulphuric acid and bichromate of sodium or potassium. The porous cup is put into the jar, and the carbon suspended through an opening in the cover which fits over the jar. This cell is excellent for telephone work; it has a high voltage, low internal resistance, and does not deteriorate on open circuit.

The gravity battery, already described, and the storage battery are used in telephone work when constant service is required. Dry cells are also used extensively, particularly in intercommunicating sets, on account of their cleanliness and convenience.

The Magneto-Generator. The above-described equipment serves to transmit and receive messages, but it is also necessary to supply some sort of calling device. The simplest apparatus for this purpose consists of an ordinary bell or buzzer operated from batteries, and this system is used commonly to-day for office sets where the distance between stations is small.

For long distances it is, however, impracticable to use this system for calling, and recourse is had to the magneto, which is described in another section. This consists of a generator having permanent field magnets and a shuttle armature which is wound with many turns of fine insulated copper wire. The armature is rotated at high speed by means of a small pinion on its shaft which meshes with a larger gear which is turned by means of a crank. This machine furnishes an alternating current, and hence it is necessary to use a polarized bell or ringer in connection with it, so constructed as to operate with an alternating current. Magneto-generators are designated by the resistance through which they will ring, being spoken of as a 10,000-ohm, 20,000-ohm generator, etc.

At the exchange it is quite common to use a power-driven magneto-generator, which may be driven from a small direct or alternating current motor. Also in some cases the motor-generator is used to supply current for ringing purposes.



KELLOGG UNIT TYPE SWITCHBOARD CABINET.

Circuits of the Telephone. A complete telephone set is made up of three distinct circuits: one for the calling apparatus, one for the transmitting apparatus, and one for the receiving apparatus. The calling apparatus includes the generator and ringer, the transmitting apparatus consists of the transmitter, batteries, and primary, and the receiving apparatus consists of the receiver and secondary of the induction coil.

When the telephone is not in use the calling apparatus must be connected with the line while the transmitting and receiving circuits are both open. On the other hand, when the telephone is used for talking, the calling circuit should be opened, the transmitting circuit should be closed, and the receiving circuit should be connected to the line. These results are accomplished automatically by means of the switch-hook upon which the receiver is hung. This hook is depressed when the receiver is in place, and raised by a spring when it is removed. In this manner the desired connections are made at the proper time.

There are two types of telephone, differing somewhat in the details of their construction and connections, known as the series telephone and the bridged telephone.

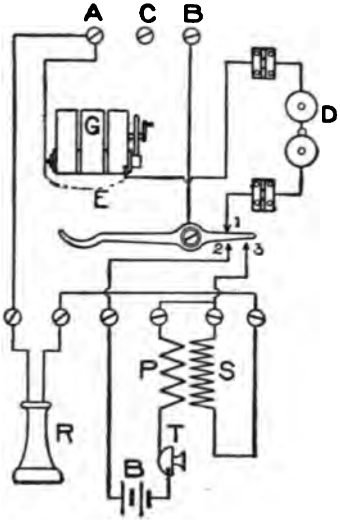


Fig. 40.

The circuits of a series telephone are shown in Fig. 40. A and B are the line terminals, and C the ground connection for the lightning arrester. When the receiver is on the hook the switch is in the position shown. The generator G and ringer D are in series across the line, through contact point 1, the generator being automatically cut out by the shunt E, when not in use. When the receiver is removed, the contact at 1 is broken, and contact is made at points 2 and 3. The primary circuit is then closed on itself, while the secondary circuit, containing the receiver and secondary of the induction coil, is cut in on the line.

Below there are three pairs of binding posts, to one pair of which the receiver R is connected, to another are connected the terminals of the primary circuit containing the transmitter T, the battery B, and primary P of the induction coil, while the secondary S of the induction coil is connected to the third pair.

Connection is made to the bell through the hinges of the box upon the door of which it is mounted. It is customary to use a ringer of 80 to 120 ohms resistance with series telephones. On account of this low resistance many series telephones cannot be bridged because it would be impossible to ring a numbei of them in multiple. Moreover, many series telephones could not be connected in series, because, since all the ringers would be constantly in the circuit, it would be impossible to talk through them. Hence this type of telephone is used almost exclusively for city exchange work, not more than two telephones being connected on a line.

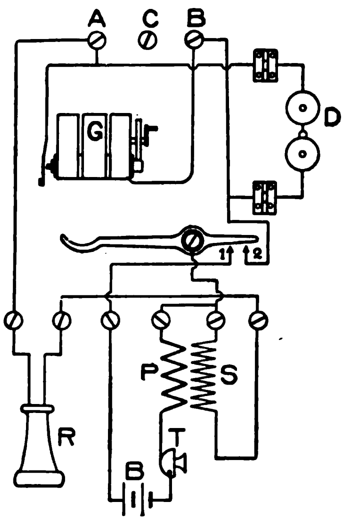
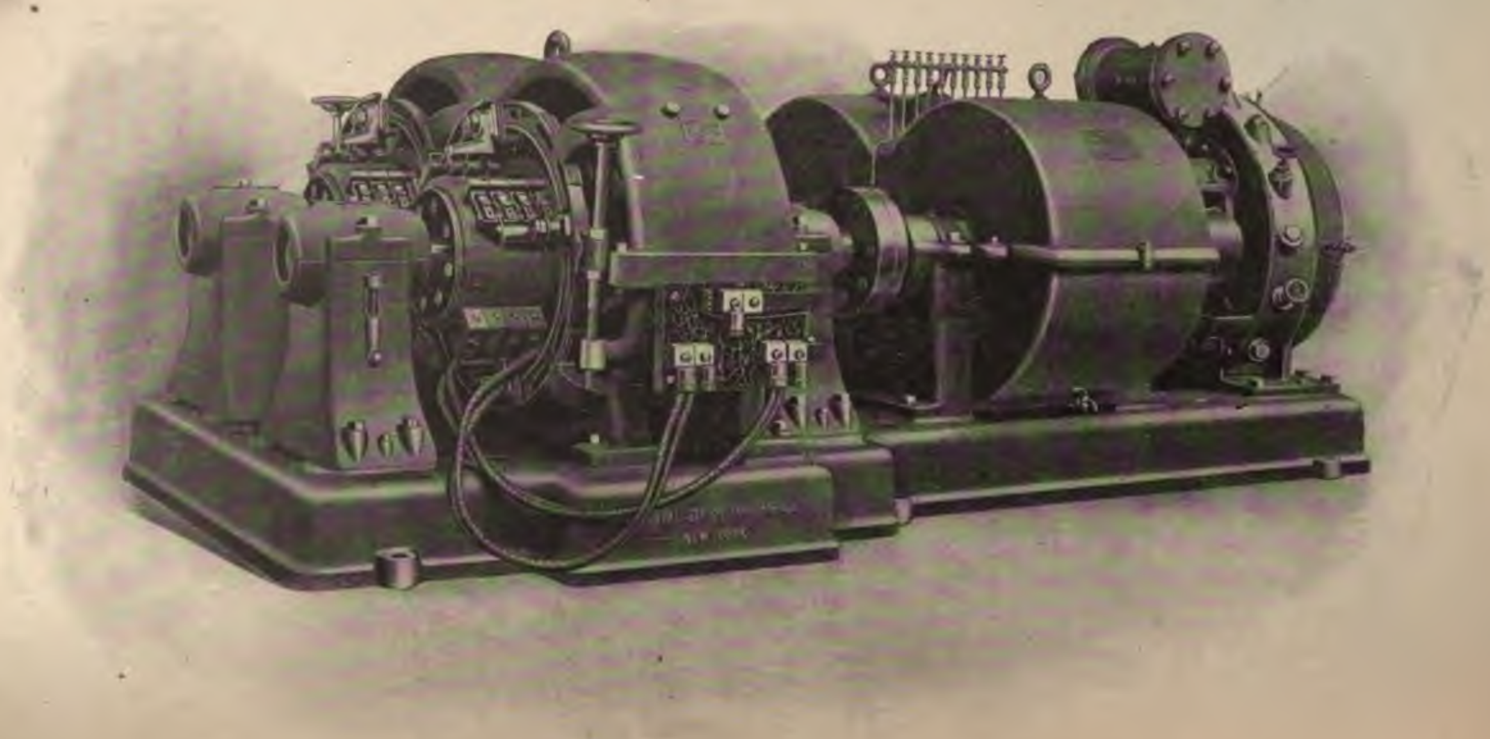


Fig. 41.

The circuits of the bridged telephone are shown in Fig. 41. The ringer coils are permanently bridged across the line. The generator is also bridged, the circuit through it being open when it is not in use, but being closed, usually automatically, when the generator is in operation. When the receiver is taken from the hook, contact is made at points 1 and 2 for the primarv and secondary circuits as in the series telephone.

The permanently bridged ringer does not interfere with the action of the receiving circuit, since its coils have a resistance of about 1600 ohms, and are wound so that their self-induction is large. Thus they offer a high impedance to the currents in the receiving circuit because of the extreme rapidity with which they alternate. For this reason a number of these telephones can be bridged upon one circuit, thus forming a party line.

There are three general methods of constructing lines, namely, the grounded circuit, the metallic circuit, and the common return. In the common return the circuit is completed through a copper wire instead of through the ground as in the grounded system, thus eliminating the noise induced by earth currents.



De Laval Steam Turbine Dynamo, 300 H. P., 200 K. W., Direct Current.

THE ELECTRIC CURRENT.

Electromotive Force. When a difference of electrical potential exists between two points, there is said to exist an *electromotive force*, or tendency to cause a current to flow from one point to the other. In the voltaic cell one plate is at a different potential from the other, which gives rise to an electromotive force between them. Also in the induction coil, an electromotive force is created in the secondary circuit caused by the action of the primary. This electromotive force is analogous to the *pressure*, caused by a difference in level of two bodies of water connected by a pipe. The pressure tends to force the water through the pipe, and the electromotive force tends to cause an electric current to flow.

The terms potential difference and electromotive force are commonly used with the same meaning, but strictly speaking the potential difference gives rise to the electromotive force. Electromotive force is commonly designated by the letters *E. M. F.* or simply *E*. It is also referred to as *pressure* or *voltage*.

Current. A current of electricity flows when two points, at a difference of potential, are connected by a wire, or when the circuit is otherwise completed. Similarly water flows from a high level to a lower one, when a path is provided. In either case the flow can take place only when the path exists. Hence to produce a current it is necessary to have an electromotive force and a closed circuit. The current continues to flow only as long as the electromotive force and closed circuit exist.

The strength of a current in a conductor is defined as the quantity of electricity which passes any point in the circuit in a unit of time.

Current is sometimes designated by the letter *C*, but the letter *I* will be used for current throughout this and following sections. The latter symbol was recommended by the International Electrical Congress held at Chicago in 1893, and has since been universally adopted.

Resistance. Resistance is that property of matter in virtue of which bodies oppose or resist the free flow of electricity. Water passes with difficulty through a small pipe of great length or through a pipe filled with stones or sand, but very readily through a large clear pipe of short length. Likewise a small wire of considerable length and made of poor conducting material offers great resistance to the passage of electricity, but a good conductor of short length and large cross section offers very little resistance.

Resistance is designated by the letter *R*.

Volt, Ampere and Ohm. The *volt* is the practical unit of electromotive force.

The *ampere* is the practical unit of current.

The *ohm* is the practical unit of resistance. The *microhm* is one millionth of an ohm and the *megohm* is one million ohms.

The standard values of the above units were very accurately determined by the International Electrical Congress in 1893, and are as follows:

The International ohm, or true ohm, as nearly as known, is the resistance of a uniform column of mercury 106.3 centimeters long and 14.4521 grams in mass, at the temperature of melting ice.

The ampere is the strength of current which, when passed through a solution of silver nitrate, under suitable conditions, deposits silver at the rate of .001118 gram per second. Current strength may be very accurately determined by electrolysis, and it is used therefore in determining the standard unit.

The volt is equal to the E. M. F. which, when applied to a conductor having a resistance of one ohm, will produce in it a current of one ampere. One volt equals $\frac{1000}{1434}$ of the E. M. F. of a Clark standard cell at 15° Centigrade.

RESISTANCE.

All substances resist the passage of electricity, but the resistance offered by some is very much greater than that offered by others. Metals have by far the least resistance and of these, silver possesses the least of any. In other words, silver is the best conductor. If the temperature remains the same, the resistance of a conductor is not affected by the current passing through it. A current of ten, twenty or any number of amperes may pass through a circuit, but its resistance will be unchanged with constant temperature. Resistance is affected by the temperature and also by the degree of hardness. Annealing decreases the resistance of a metal.

Conductance is the inverse of resistance; that is, if a conductor has a resistance of R ohms, its conductance is equal to $\frac{1}{R}$.

Resistance Proportional to Length. The resistance of a conductor is directly proportional to its length. Hence, if the length of a conductor is doubled, the resistance is doubled, or if the length is divided, say into three equal parts, then the resistance of each part is one third the total resistance.

Example. — The resistance of 1283 feet of a certain wire is 6.9 ohms. What is the resistance of 142 feet of the same wire?

Solution. — As the resistance is directly proportional to the length we have the proportion,

$$\text{required resistance} : 6.9 : : 142 : 1283$$

or,
$$\frac{\text{required resistance}}{6.9} = \frac{142}{1283}$$

Hence,
$$\text{required resistance} = 6.9 \times \frac{142}{1283}$$
$$= .76 \text{ ohm (approx.)}$$

Ans. .76 ohm.

Example. — The resistance of a wire having a length of 521 feet is .11 ohm. What length of the same wire will have a resistance of .18 ohm?

Solution. — As the resistance is proportional to length, we have the proportion,

$$\text{required length} : 521 : : .18 : .11$$

or,
$$\frac{\text{required length}}{521} = \frac{.18}{.11}$$

Hence,
$$\text{required length} = 521 \times \frac{.18}{.11}$$
$$= 852 \text{ feet (approx.)}$$

Ans. 852 feet.

Resistance Inversely Proportional to Cross-Section. The resistance of a conductor is inversely proportional to its cross-sectional area. Hence the greater the cross-section of a wire the less is its resistance. Therefore, if two wires have the same length, but one has a cross-section three times that of the other, the resistance of the former is one-third that of the latter.

Example. — The ratio of the cross-sectional area of one wire to that of another of the same length and material is $\frac{257}{101}$. The resistance of the former is 16.3 ohms. What is the resistance of the latter?

Solution. — As the resistances are inversely proportional to the cross-sections, the smaller wire has the greater resistance, and we have the proportion:

$$\text{required resist.} : 16.3 :: 257 : 101$$

or,

$$\frac{\text{required resist.}}{16.3} = \frac{257}{101}$$

Hence,

$$\text{required resist.} = 16.3 \times \frac{257}{101}$$

$$= 41.5 \text{ ohms (approx.)}$$

Ans. 41.5 ohms.

Example. — If the resistance of a wire of a certain length and having a cross-sectional area of .0083 square inch is 1.7 ohms, what would be its resistance if the area of its cross-section were .092 square inch?

Solution. — Since increasing the cross-sectional area of a wire decreases its resistance, we have the proportion,

$$\text{required resist.} : 1.7 :: .0083 : .092$$

or,

$$\frac{\text{required resist.}}{1.7} = \frac{.0083}{.092}$$

Hence,

$$\text{required resist.} = 1.7 \times \frac{.0083}{.092}$$

$$= .15 \text{ ohm (approx.)}$$

Ans. .15 ohm.

As the area of a circle is proportional to the square of its diameter, it follows that the resistances of round conductors are inversely proportional to the squares of their diameters.

Example. — The resistance of a certain wire having a diam.

eter of .1 inch is 12.6 ohms. What would be its resistance if the diameter were increased to .32 inch?

Solution. — The resistances being inversely proportional to the squares of the diameters, we have,

$$\text{required resist.} : 12.6 :: .1^2 : .32^2$$

or,
$$\frac{\text{required resist.}}{12.6} = \frac{.1^2}{.32^2}$$

Hence,
$$\text{required resist.} = 12.6 \times \frac{.1^2}{.32^2}$$
$$= \frac{12.6 \times .01}{.1024}$$
$$= 1.23 \text{ ohms (approx.)}$$

Ans. 1.23 ohms.

Specific Resistance. The specific resistance of a substance is the resistance of a portion of that substance of unit length and unit cross-section at a standard temperature. The unit commonly used is the centimeter or inch, and the temperature that of melting ice. The specific resistance may therefore be said to be the resistance (usually stated in microhms) of a centimeter cube or inch cube at the temperature of melting ice. If the specific resistances of two substances are known then their relative resistance is given by the ratio of the specific resistances.

Conductivity is the reciprocal of specific resistance.

Example. — A certain copper wire at the temperature of melting ice has a resistance of 29.7 ohms. Its specific resistance (resistance of 1 centimeter cube in microhms) is 1.594, and that of platinum is 9.032. What would be the resistance of a platinum wire of the same size and length of the copper wire, and at the same temperature?

Solution. — The resistance would be in direct ratio of the specific resistances, and we have the proportion:

$$\text{required resist.} : 29.7 :: 9.032 : 1.594$$

Hence,
$$\text{required resist.} = 29.7 \times \frac{9.032}{1.594}$$
$$= 168. \text{ ohms (approx.)}$$

Ans. 168. ohms.

Calculation of Resistance. From the preceding pages it is evident that resistance varies directly as the length, inversely as the cross-sectional area, and depends upon the specific resistance of the material. This may be expressed conveniently by the formula,

$$R = s\frac{L}{A}$$

in which R is the resistance, L the length of the conductor, A the area of its cross section, and s the specific resistance of the material.

Example.— A telegraph relay is wound with 1,800 feet of wire .010 inch in diameter, and has a resistance of 150 ohms. What will be its resistance if wound with 400 feet of wire .022 inch in diameter?

Solution.— If the wires were of equal length, we should have the proportion,

$$\text{Required resistance} : 150 :: (.010)^2 : (.022)^2$$

or, $$\text{Required resistance} = 150 \times \frac{(.010)^2}{(.022)^2} = 30.99+ \text{ ohms.}$$

For a wire 400 feet long, we have, therefore, by direct proportion,

$$\text{Required resistance} = \frac{400}{1,800} \times 30.99 = 6.88+.$$

Ans. 6.88+ ohms.

If a circuit is made up of several different materials joined in series with each other, the resistance of the circuit is equal to the sum of the resistances of its several parts. In calculating the resistance of such a circuit, the resistance of each part should first be calculated, and the sum of these resistances will be the total resistance of the circuit.

The table on page 9 gives the resistance of chemically pure substances at 0° Centigrade or 32° Fahrenheit in International ohms. The first column of numbers gives the relative resistances when that of annealed silver is taken as unity. For example, mercury has 62.73 times the resistance of annealed silver. The second and third columns give the resistances of a foot of wire .001 inch in diameter, and of a meter of wire 1 millimeter in diameter, respectively. The fourth and fifth columns give respectively the resistance in microhms of a cubic inch and cubic centimeter, that is, the specific resistances.

Table Showing Relative Resistance of Chemically Pure Substances at Thirty-two Degrees Fahrenheit in International Ohms.

Metal.	Relative Resistance.	Resistance of a wire 1 foot long, .001 inch in diameter.	Resistance of a wire 1 meter long, 1 millimeter in diameter.	Resistance in Microhms.	
				Cubic Inch.	Cubic Centimeter.
Silver, annealed.	1.000	9.023	.01911	.5904	1.500
Copper, annealed.	1.063	9.585	.02028	.6274	1.594
Silver, hard drawn.	1.086	9.802	.02074	.6415	1.629
Copper, hard drawn.	1.086	9.803	.02075	.6415	1.629
Gold, annealed.	1.369	12.35	.02613	.8079	2.052
Gold, hard drawn.	1.393	12.56	.02661	.8224	2.088
Aluminum, annealed	1.935	17.48	.03700	1.144	2.904
Zinc, pressed.	3.741	33.76	.07143	2.209	5.610
Platinum, annealed.	6.022	54.34	.1150	3.555	9.032
Iron, annealed.	6.460	58.29	.1234	3.814	9.689
Lead, pressed.	13.05	117.7	.2491	7.706	19.58
German silver.	13.92	125.5	.2659	8.217	20.87
Platinum-silver alloy (⅓ platinum, ⅔ silver.)	16.21	146.3	.3097	9.576	24.32
Mercury.	62.73	570.7	1.208	37.05	94.06

It should be noted that the resistances in the above table are for chemically pure substances, and also at 32° Fahrenheit. A very small portion of foreign matter mixed with a metal greatly increases its resistance. An alloy of two or more metals always has a higher specific resistance than that of any of its constituents. For example, the conductivity of silver mixed with 1.2 per cent in volume of gold, will be 59 when that of pure silver is taken as 100. Annealing reduces the resistance of metals.

The following examples are given to illustrate the use of the table above in connection with the formula at the top of page 8, and to show the application of preceding laws.

Example.—From the specific resistance of annealed aluminum as given in the next to the last column of the table, calculate the resistance given in the second column of figures for that substance.

Solution.—The resistance in microhms of a cubic inch of annealed aluminum at 32° F. is 1.144, which is equal to .000001144 ohms. The resistance of a wire 1 foot long and .001

inch in diameter is required. In the formula on page 8, we have $s = .000001144$, $L = 1$ foot $= 12$ inches and

$$A = \frac{\pi d^2}{4} = \frac{3.1416 \times .001^2}{4} = .0000007854 \text{ sq. in.}$$

Substituting these values in the formula,

$$R = s\frac{L}{A}$$

we have,

$$R = .000001144 \times \frac{12}{.0000007854}$$

$$= 17.48 \text{ ohms.}$$ Ans. 17.48 ohms.

Example.—The resistance in microhms of a cubic centimeter of annealed platinum at 32° F. is 9.032. What is the resistance of a wire of the same substance one meter long and one millimeter in diameter at the same temperature?

Solution.—In the formula for resistance we have the quantities $s = 9.032$ microhms $= .000009032$ ohms; $L = 1$ meter $=$ 100 centimeters; and

$$A = \frac{\pi d^2}{4} = \frac{3.1416 \times .1^2}{4} = .007854 \text{ sq. cm.}$$

the diameter being equal to 1 millimeter = .1 cm.

Substituting these values we have,

$$R = .000009032 \times \frac{100}{.007854}$$

$$= .1150 \text{ ohms.}$$ Ans. .115 ohms.

Example.—From the table the resistance of 1 ft. of pure annealed silver wire .001 inch in diameter at 32° F. is 9.023 ohms. What is the resistance of a mile of wire of the same substance .1 inch in diameter at that temperature?

Solution.—As the resistance of wires is directly proportional to their length and inversely proportional to the squares of their diameters, the required resistance is found by multiplying the resistance per foot by 5,280 and the product by the inverse squares of the diameters.

Therefore $R = 9.023 \times 5280 \times \left\{\frac{.001}{.1}\right\}^2$

$= 4.76$ ohms (approx.)

Ans. 4.76 ohms.

Example.—A mile and one-half of an annealed wire of pure iron has a resistance of 46.1 ohms. What would be the resistance of hard drawn wire of pure copper of the same length and diameter, assuming each to be at the temperature of melting ice?

Solution.—The only factor involved by this example is the relative resistance of the two metals. From the table, page 9, annealed iron has 6.460 and hard-drawn copper 1.086 times the resistance of annealed silver. Hence the resistance of the copper is to that of the iron as 1.086 is to 6.460, and the required resistance is

$$R = 46.1 \times \frac{1.086}{6.460} = 7.75 \text{ ohms (approx.)}$$

Ans. 7.75 ohms.

Example.—If the resistance of a wire 7,423 feet long is 18.7 ohms, what would be its resistance if its length were reduced to 6,253 feet and its cross-section made one half again as large?

Solution.—As resistance is directly proportional to the length, and inversely proportional to the area of the cross-section, the required resistance is

$$R = 18.7 \times \frac{6253}{7423} \times \frac{2}{3} = 10.5 \text{ ohms (approx.)}$$

Ans. 10.5 ohms.

Resistance Affected by Heating. The resistance of metals depends upon the temperature, and the resistance is increased by heating. The heating of some substances, among which is carbon, causes a decrease in their resistance. The resistance of the filament of an incandescent lamp when lighted is only about half as great as when cold. All *metals*, however, have their resistance increased by a rise in temperature. The percentage increase in resistance with rise of temperature varies with the different metals, and varies slightly for the same metal at different temperatures. The increase is practically uniform for most metals throughout a considerable range of temperature. The resistance of copper increases about .4 per cent. per degree Centigrade, or about .22 per cent. per degree Fahrenheit. The percentage increase in resistance for alloys is much less than for the simple metals. Standard resistance coils are therefore made of alloys, as it is desirable that their resistance should be as nearly constant as possible.

The change in resistance of one ohm per degree rise in temperature for a substance is called the *temperature coefficient* for that substance. The following table gives the temperature coefficients for a few substances.

TEMPERATURE COEFFICIENTS.

MATERIAL.	RISE IN R. OF 1 OHM WHEN HEATED: 1° F.	1° C.
Platinoid	.00012	.00022
Platinum-silver	.00014	.00025
German silver	.00022	.00040
Platinum	.0019	.0035
Silver	.0021	.0038
Copper, aluminum	.0022	.0040
Iron	.0026	.0046

If the resistance of a conductor at a certain temperature is known, the resistance the conductor will have at a higher temperature may be found by multiplying the temperature coefficient for the substance, by the number of degrees increase and by the resistance at the lower temperature, and adding to this result the resistance at the lower temperature. The product of the temperature coefficient by the number of degrees increase gives the increase in resistance of one ohm through that number of degrees, and multiplying this by the number of ohms gives the increase in resistance for the conductor. The result obtained is practically correct for moderate ranges of temperature.

The above method of calculating the resistance of conductors at increased temperatures is conveniently expressed by the following formula:

$$R_2 = R_1 \ (1 + a\ t)$$

where R_2 is the resistance at the higher temperature, R_1 that at the lower temperature, a the temperature coefficient for the substance and t the number of degrees change.

From the preceeding formula it follows that if the resistance at the higher temperature is known, that at the lower temperature will be given by the formula:

$$R_1 = \frac{R_2}{1 + at}$$

In calculating resistances at different temperatures, the temperature coefficient based on the Fahrenheit scale should be used if the number of degrees change is given in degrees Fahrenheit. and that based on the Centigrade scale if given in degrees Centigrade.

Example.— The resistance of a coil of German silver wire at 12° C. is 1304 ohms. What would be its resistance at a temperature of 60° C.?

Solution.— From the statement of the example $R_1 = 1304$, $t = 60 - 12 = 48$, and from the table page 12, $a = .0004$. Substituting these values in the first of the preceding formulas we have,

$$\begin{aligned} R_2 &= 1304\,(1 + .0004 \times 48) \\ &= 1304 \times 1.0192 \\ &= 1329 \text{ ohms (approx.)} \end{aligned}$$

Ans. 1329 ohms.

Example. — If the resistance of a copper conductor at 95° F. is 48.2 ohms, what would be the resistance of the same conductor at 40° F.?

Solution. — In this case $R_2 = 48.2$, $t = 95 - 40 = 55$, and from the table $a = .0022$. Substituting these values in the formula at the foot of page 12, we have,

$$\begin{aligned} R_1 &= \frac{48.2}{1 + .0022 \times 55} = \frac{48.2}{1.121} \\ &= 43. \text{ ohms (approx.)} \end{aligned}$$

Ans. 43 ohms.

The first table on page 14 gives the resistance of the most common sizes of copper wire according to the American or Brown and Sharpe (B. & S.) gauge. The resistance given is for pure copper wire at a temperature of 75° F. or 24° C.

The first column gives the number of the wire, the second the diameter in thousandths of an inch or mils, and the third the diameter in millimeters, The fourth column gives the equivalent number of wires each one mil or one thousandth of an inch in diameter. This is called the size of the wire in circular mils and is equal to the square of the diameter in mils. The fifth column gives the ohms per thousand feet and the resistance per mile is found by multiplying these values by 5.28. Ordinary commercial copper has a conductivity of about 95 to 97 per cent. of that of pure copper. The resistance of commercial wire is therefore about 3 to 5 per cent. greater than the values given in the table. The resistance for any metal other than copper may be found by multiplying the resistance given in the table by the ratio of the specific resistance of the given metal to the specific resistance of copper.

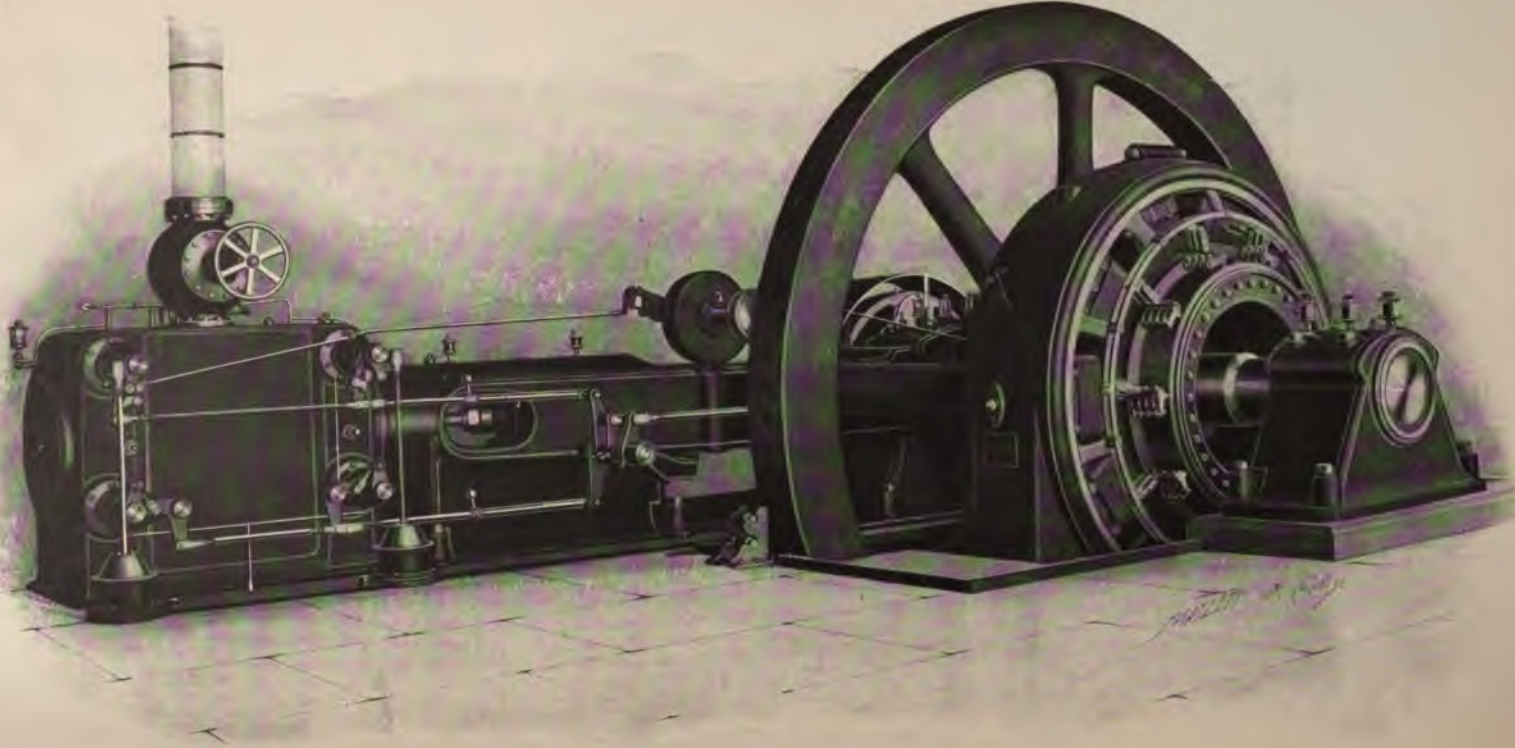
American Wire Gauge (B. & S.)

No.	Diameter in		Circular Mils.	Ohms per 1000 Ft.	No.	Diameter in		Circular Mils.	Ohms per 1000 Ft.
	Mils.	Millim.				Mils.	Millim.		
0000	460.00	11.684	211600.0	.051	19	35.89	.912	1288.0	8.617
000	409.64	10.405	167805.0	.064	20	31.96	.812	1021.5	10.566
00	364.80	9.266	133079.4	.081	21	28.46	.723	810.1	13.323
0	324.95	8.254	105592.5	.102	22	25.35	.644	642.7	16.799
1	289.30	7.348	83694.2	.129	23	22.57	.573	509.5	21.185
2	257.63	6.544	66373.0	.163	24	20.10	.511	404.0	26.713
3	229.42	5.827	52634.0	.205	25	17.90	.455	320.4	33.684
4	204.31	5.189	41742.0	.259	26	15.94	.405	254.0	42.477
5	181.94	4.621	33102.0	.326	27	14.19	.361	201.5	53.563
6	162.02	4.115	26250.5	.411	28	12.64	.321	159.8	67.542
7	144.28	3.665	20816.0	.519	29	11.26	.286	126.7	85.170
8	128.49	3.264	16509.0	.654	30	10.03	.255	100.5	107.391
9	114.43	2.907	13094.0	.824	31	8.93	.227	79.7	135.402
10	101.89	2.588	10381.0	1.040	32	7.95	.202	63.2	170.765
11	90.74	2.305	8234.0	1.311	33	7.08	.180	50.1	215.312
12	80.81	2.053	6529.9	1.653	34	6.30	.160	39.7	271.583
13	71.96	1.828	5178.4	2.084	35	5.61	.143	31.5	342.443
14	64.08	1.628	4106.8	2.628	36	5.00	.127	25.0	431.712
15	57.07	1.450	3256.7	3.314	37	4.45	.113	19.8	544.287
16	50.82	1.291	2582.9	4.179	38	3.96	.101	15.7	686.511
17	45.26	1.150	2048.2	5.269	39	3.53	.090	12.5	865.046
18	40.30	1.024	1624.1	6.645	40	3.14	.080	9.9	1091.865

The following table gives the size of the English or Birmingham wire gauge. The B. & S. is however much more frequently used in this country. The Brown and Sharpe gauge is a little smaller than the Birmingham for corresponding numbers.

Stubs' or Birmingham Wire Gauge (B. W. G.)

No.	Diameter in		No.	Diameter in		No.	Diameter in	
	Mils.	Millim.		Mils.	Millim.		Mils.	Millim.
0000	454	11.53	8	165	4.19	18	49	1.24
00	380	9.65	10	134	3.40	20	35	0.89
1	300	7.62	12	109	2.77	24	22	0.55
4	238	6.04	14	83	2.11	30	12	0.31
6	203	5.16	16	65	1.65	36	4	0.10



SINGLE-CYLINDER RICE AND SARGENT ENGINE.

Direct-Connected to Generator.

Providence Engineering Works.

EXAMPLES FOR PRACTICE.

1. What is the resistance of an annealed silver wire 90 feet long and .2 inch in diameter at 32° F.? Ans. .02+ ohm.

2. What is the resistance of 300 meters of annealed iron wire 4 millimeters in diameter when at a temperature of 0° C.? Ans. 2.31+ ohms.

3. What is the resistance of 2 miles of No. 27 (B. & S.) pure copper wire at 75° F.? Ans. 565.+ ohms.

4. The resistance of a piece of copper wire at 32°F. is 3 ohms. What is its resistance at 49°F.? Ans. 3.11+ ohms.

5. The resistance of a copper wire at 52°F. is 7 ohms. What is its resistance at 32°F.? Ans. 6.70+ ohms.

6. What is the resistance of 496 ft. of No. 10 (B. & S.) pure copper wire at 45°F.? Ans. .483+ ohms.

On pages 16 and 17 is given a table disclosing among other data the resistance of various primary cells. The resistance of a circuit of which a battery forms a part, is made up of the external resistance, or the resistance of outside wires and connections, and the internal resistance, or the resistance of the battery itself. The table referred to gives in the first column the name of the cell. In the second and third column appears the name of the anode and kathode respectively. These terms are commonly used with reference to electrolysis but may also be applied to primary cells. The current passes from the anode to the kathode through the cell, and therefore with reference to the cell itself, the anode may be considered the positive element and the kathode the negative element. In regard to the outside circuit however, the current passes of course, from the kathode to the anode, and hence with reference to the outside circuit the kathode is positive and the anode negative; ordinarily the external circuit is considered. As the anode of almost all primary cells is zinc it may readily be remembered that the current passes from the other element *to* the zinc through the *external* circuit. The fourth and fifth columns of the table give the excitant and depolarizer respectively. The sixth column gives the E. M. F. of each cell when it is supplying no current, and the last column gives the internal resistance in ohms.

TABLE IN RELATION TO PRIMARY CELLS, ELECTROMOTIVE FORCE, RESISTANCE, ETC.

NAME OF CELL.	ANODE.	KATHODE.	EXCITANT.	DEPOLARIZER.	E. M. F. IN VOLTS.	INTERNAL RESISTANCE IN OHMS.
Volta (Wollaston, etc.)	Zinc	Copper	Solution of Sulphuric Acid (H_2SO_4)	None	1 to 0.5	
Smee	Zinc	Platinized Silver	Solution of Sulphuric Acid (H_2SO_4)	None	1 to 0.5	0.5
Law	Zinc	Carbon	Solution of Sulphuric Acid (H_2SO_4)	None	1 to 0.5	
Poggendorff (Grenet)	Zinc	Graphite (Carbon)	Solution of Sulphuric Acid (H_2SO_4)	Potassium Dichromate ($K_2Cr_2O_7$)	2.1	
Poggendorff (Grenet) two fluid	Zinc	Graphite (Carbon)	Saturated Solution of Potassium Dichromate and Sulphuric Acid	None Separate	1.98	.001 to .08
Grove	Zinc	Platinum	Sulphuric Acid dilute (H_2SO_4)	Nitric Acid (HNO_3)	1.96	0.1 to 0.12
Bunsen	Zinc	Graphite (Carbon)	Sulphuric Acid dilute (H_2SO_4)	Nitric Acid Chromic Acid	1.8 to 1.98 1.8	0.08 to 0.11 0.1 to 0.12
Leclanche	Zinc	Graphite (Carbon)	Ammonium Chloride (NH_4Cl)	Manganese Dioxide (MnO_2)	1.4 to 1.6	1.13 to 1.1[illegible]
Lalande Lalande—Chaperon	Zinc	Graphite (Carbon)	Caustic Potash or Potassium Hydrate (KOH)	Cupric Oxide	0.8 to 0.98	1.3
Upward	Zinc	Graphite (Carbon)	Zinc Chloride ($ZnCl_2$)	Chlorine (Cl)	2.0	
Fitch	Zinc	Graphite (Carbon)	Ammonium Chloride (NH_4Cl)	Sodium & Potassium Chlorates ($NaClO_3$ + $KClO_3$)	1.1	
Papst	Iron	Graphite (Carbon)	Ferric Chloride (Fe_2Cl_6)	(Fe_2Cl_6)	0.4	
Obach (dry)	Zinc	Graphite (Carbon)	Ammonium Chloride (NH_4Cl) in Calcium Sulphate ($CaSO_4$)	Manganese Dioxide (MnO_2)	1.46	
Daniell (Meidinger Minotto, etc.)	Zinc	Copper	Zinc Sulphate ($ZnSO_4$)	Copper Sulphate ($CuSO_4$)	1.079	2 to 5
De la Rue	Zinc	Silver	Ammonium Chloride	Silver Chloride (AgCl)	1.03 to 1.42	0.4 to 0.6
Marie Davy	Zinc	Graphite (Carbon)	Sulphuric Acid dilute (H_2SO_4)	Paste of Sulphate of Mercury (Hg_2SO_4)	1.52	0.75 to 1
Clark (Standard)	Zinc	Mercury	Zinc Sulphate ($ZnSO_4$)	Mercurous Sulphate (Hg_2SO_4)	1.434*	0.2 to 0.5
Weston	Cadmium	Mercury	Cadmium Sulphate ($CdSO_4$)	Mercurous Sulphate (Hg_2SO_4)	1.025	

NAME OF CELL.	ANODE.	KATHODE.	EXCITANT.	DEPOLARISER.	E. M. F. IN VOLTS.	INTERNAL RESISTANCE IN OHMS.
Von Helmholtz	Zinc	Mercury	Zinc Chloride ($ZnCl_2$)	Mercurous Chloride (Hg_2Cl_2)	1.6	
Chromic Acid single fluid	Zinc	Graphite (Carbon)	Sulphuric and Chromic Acids, dilute mixed	None Separate	2.2	.016 to .06
Fuller	Zinc	Graphite (Carbon)	Sulphuric Acid (H_2SO_4)	Potassium Dichromate ($K_2Cr_2O_7$)	2.0	0.5 to 0.7
Gaiffe	Zinc	Silver	Zinc Chloride ($ZnCl_2$)	Silver Chloride ($AgCl$)	1.02	0.5 to 0.6
Maiche	Zinc scraps in bath of Mercury	Platinized Carbon	Common Salt Solution *i. e.* Sodium Chloride ($NaCl$)	None Separate	1.25	1 to 2
Niaudet	Zinc	Graphite (Carbon)	Common Salt Solution *i. e.* Sodium Chloride ($NaCl$)	Chloride of Calcium (Lime) ($CaCl_2$)	1.0 to 1.6	5 to 6
Schanschieff	Zinc	Graphite (Carbon)	Mercurial Solution	None Separate	1.56	0.05 to 0.75
Skrivanoff	Zinc	Silver	Caustic Potash or Potassium Hydrate (KOH)	Chloride of Silver ($AgCl$)	1.5	1.5

* At 15 degrees Centigrade or 59 degrees Fahrenheit.

Resistances in last column measured in cells standing 6″ × 4″

OHM'S LAW.

One of the most important and most used laws of electricity is that first formulated by Dr. G. S. Ohm, and known as Ohm's law. This law is as follows:

The current is directly proportional to the electromotive force and inversely proportional to the resistance.

That is, if the electromotive force applied to a circuit is increased, the current will be increased in the same proportion, and if the resistance of a circuit is increased then the current will be decreased proportionally. Likewise a decrease in the electromotive force causes a proportional decrease in current and a decrease in resistance causes a proportional increase in current. The current depends only upon the electromotive force and resistance and in the manner expressed by the above simple law. The law may be expressed algebraically as follows:

$$\text{current } \textit{varies as } \frac{\text{electromotive force}}{\text{resistance}}$$

The units of these quantities, the ampere, volt and ohm, have been so chosen that an electromotive force of 1 volt applied to a resistance of 1 ohm, causes 1 ampere of current to flow. Ohm's law may therefore be expressed by the following equation:

$$I = \frac{E}{R}$$

where I is the current in amperes, E the electromotive force in volts and R the resistance in ohms.

It is therefore evident, that if the electromotive force and resistance are known the current may be found, or if any two of the three quantities are known the third may be found. If the current and resistance are known the electromotive force may be found from the formula:

$$E = R\,I$$

and if the current and electromotive force are known, the resistance may be found from the formula:

$$R = \frac{E}{I}$$

Simple Applications. The following examples are given to illustrate the simplest applications of Ohm's law.

Example. — If the E.M.F. applied to a circuit is 4 volts and its resistance is 2 ohms, what current will flow?

Solution. — By the formula for current,

$$I = \frac{E}{R} = \frac{4}{2} = 2 \text{ amperes.}$$

Ans. 2 amperes.

Example. — What voltage is necessary to cause a current of 23 amperes to flow through a resistance of 820 ohms?

Solution. — By the formula for E.M.F.,

$$E = RI = 820 \times 23 = 18{,}860 \text{ volts.}$$

Ans. 18,860 volts.

Example. — The E.M.F. applied to a circuit is 110 volts, and it is desired to obtain a current of .6 ampere. What should be the resistance of the circuit?

Solution. — By the formula for resistance,

$$R = \frac{E}{I} = \frac{110}{.6} = 183.+ \text{ ohms.}$$

Ans. 183 ohms.

Series Circuits. A circuit made up of several parts all joined in series with each other, is called a series circuit and the resistance of the entire circuit is of course the sum of the separate resistances. In calculating the current in such a circuit the total resistance must first be obtained, and the current may then be found by dividing the applied or total E.M.F. by the total resistance. This is expressed by the formula,

$$I = \frac{E}{R_1 + R_2 + R_3 + \text{etc.}}$$

Example. — Three resistance coils are connected in series with each other and have a resistance of 8, 4 and 17 ohms respectively. What current will flow if the E.M.F. of the circuit is 54 volts?

Solution. — By the preceding formula,

$$I = \frac{E}{R_1 + R_2 + R_3} = \frac{54}{8 + 4 + 17} = \frac{54}{29} = 1.8+ \text{ amperes.}$$

Ans. 1.8+ amperes.

Example. — Six arc lamps, each having a resistance of 5 ohms, are connected in series with each other and the resistance of the connecting wires and other apparatus is 3.7 ohms. What must be the pressure of the circuit to give a desired current of 9.6 amperes?

Solution. — The total resistance of the circuit is $R = (6 \times 5) + 3.7 = 33.7$ ohms and the current is to be $I = 9.6$ amperes. Hence by the formula for E.M.F.,

$$E = R\,I = 33.7 \times 9.6 = 323.+ \text{ volts.}$$

Ans. 323.+ volts.

Example. — The current passing in a certain circuit was 12 amperes and the E.M.F. was 743 volts. The circuit was made up of 4 sections all connected in series, and the resistance of three sections was 16, 9 and 26 ohms respectively. What was the resistance of the fourth section?

Solution. — Let x = the resistance of the fourth section, then $R = 16 + 9 + 26 + x = 51 + x$, $I = 12$, and $E = 743$. By the formula for resistance,

$$R = \frac{E}{I} \text{ or, } 51 + x = \frac{743}{12} = 61.9 \text{ ohms (approx.)}$$

If $51 + x = 61.9$ we have, by transposing 51 to the other side of the equation,

$$x = 61.9 - 51 = 10.9 \text{ ohms.}$$

Ans. 10.9 ohms.

Example. — A current of 54 amperes flowed through a circuit when the E.M.F. was 220 volts. What resistance should be added in series with the circuit to reduce the current to 19 amperes?

Solution. — The resistance in the first case was,

$$R = \frac{220}{54} = 4.07 \text{ ohms (approx.)}$$

The resistance in the second must be,

$$R = \frac{220}{19} = 11.58 \text{ ohms (approx.)}$$

The required resistance to insert in the circuit is the difference of these two resistances, or $11.58 - 4.07 = 7.51$ ohms.

Ans. 7.51 ohms.

Fall of Potential in a Circuit. Fig. 1 illustrates a series circuit in which the resistances A, B, C, D and E are connected in series with each other and with the source of electricity. If the E. M. F. is known, the current may be found by dividing the E. M. F. by the sum of all the resistances. Ohm's law may, however, be applied to any part of a circuit separately, as well as to the complete circuit. Suppose the resistances of A, B, C, D and E are 4, 3, 6, 3 and 4 ohms respectively, and assume that the source has no resistance. Suppose the current flowing to be 12 amperes. The E. M. F. necessary to force a current of 12 amperes through the resistance A of 4 ohms is, by applying Ohm's law, equal to $E = RI = 4 \times 12 = 48$ volts. Hence between the points a and b outside of the resistance A, there must be a difference of potential of 48 volts to force the current through this resistance. Also to force the same current through B, the voltage necessary is $3 \times 12 = 36$. Similarly, for each part C, D and E, there are required 72, 36 and 48 volts respectively.

As 48 volts are necessary for part A and 36 volts for part B, it is evident that to force the current through both parts a difference of potential of $48 + 36 = 84$ volts is required; that is, the voltage between the points *a* and *c* must be 84 volts. For the three parts *A*, *B* and *C*, $48 + 36 + 72 = 156$ volts are necessary, and for the entire circuit, 240 volts must be applied to give the current of 12 amperes. From the above it is evident that there is a gradual fall of potential throughout the circuit, and if the voltage between any two points of the circuit be measured, the E. M. F. obtained would depend upon the resistance included between these two points. For example, the voltage between points *b* and *d* would be found to be $72 + 36 = 108$ volts, or between *d* and *e* 36, volts, etc. From the preceding it is apparent that the fall of potential in a part of a circuit is equal to the current multiplied by the resistance of that part.

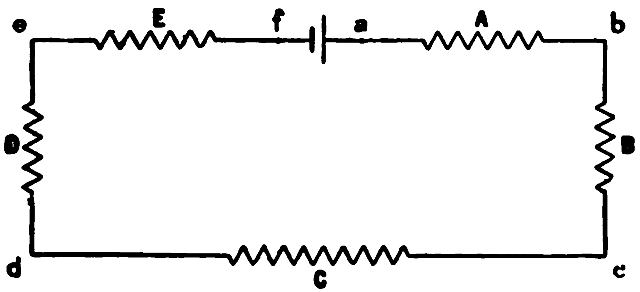


Fig. 1.

This gradual fall of potential, or *drop* as it is commonly called, throughout a circuit, enters into the calculations for the size of conductors or mains supplying current to distant points. The resistances of the conductors cause a certain drop in transmitting the current, depending upon their size and length, and it is therefore necessary that the voltage of machines at the supply station shall be great enough to give the voltage necessary at the receiving stations as well as the additional voltage lost in the conducting mains.

For example, in Fig. 1 the voltage necessary between the points *e* and *b* is 144 volts, but to give this voltage the source must supply in addition the voltage lost in parts *A* and *E*, which equals 96 volts.

Example.—The voltage required by 17 arc lamps connected in series is 782 volts and the current is 6.6 amperes. The res·

ance of the connecting wires is 7 ohms. What must be the E. M. F. applied to the circuit?

Solution.—The drop in the connecting wires is $E = RI = 7 \times 6.6 = 46.2$ volts. The E. M. F. necessary is therefore $782 + 46.2 = 828.2$ volts. Ans. 828.2 volts.

Example.—The source of E. M. F. supplies 114 volts to a circuit made up of incandescent lamps and conducting wires. The lamps require a voltage of 110 at their terminals, and take a current of 12 amperes. What should be the resistance of the conducting wires in order that the lamps will receive the necessary voltage?

Solution.—The allowable drop in the conducting wires is $114 - 110 = 4$ volts. The current to pass through the wires is 12 amperes. Hence the resistance must be

$$R = \frac{E}{I} = \frac{4}{12} = .33 + \text{ohms.}$$

Ans. .33 + ohms.

Divided Circuits. When a circuit divides into two or more parts, it is called a *divided* circuit and each part will transmit a portion of the current.

Such a circuit is illustrated in Fig. 2, the two branches being represented by *b* and *c*. The current passes from the positive pole of the battery through *a* and then divides; part of the current passing through *b* and part through *c*. The current then unites and passes through *d* to the negative pole of the battery. The part *c* may be considered as the main part of the circuit and *b* as a by-pass about it. A branch which serves as a by-pass to another circuit is called a *shunt* circuit, and the two branches are said to be connected in *parallel*.

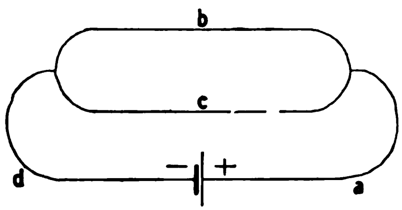


Fig. 2.

In considering the passage of a current through a circuit of this sort, it may be necessary to determine how much current will pass through one branch and how much through the other. Evidently this will depend upon the relative resistance of the two branches, and more current will pass through the branch offering the lesser resistance than through the branch having the higher resistance. If the two parts have equal resistances, then one half of the total current will pass through each branch. If one branch has twice the resistance of the other, then only one-half as much of the total current will pass through that branch as through the other; that is, $\frac{1}{3}$ of the total current will pass through the first branch and the remaining $\frac{2}{3}$ will pass through the second.

The relative strength of current in the two branches will be inversely proportional to their resistances, or directly proportional to their conductances.

Suppose the resistance of one branch of a divided circuit is r_1 (see Fig. 3), and that of the other is r_2. Then by the preceding law,

$$\text{current in } r_1 : \text{current in } r_2 : : r_2 : r_1$$

Also,

$$\text{current in } r_1 : \text{total current} : : r_2 : r_1 + r_2$$

and

$$\text{current in } r_2 : \text{total current} : : r_1 : r_1 + r_2$$

Let I represent the total current, i_1 the current through the resistance r_1 and i_2 the current through the resistance r_2. Then the two preceding proportions are expressed by the following formulas:

$$i_1 = \frac{Ir_2}{r_1 + r_2} \quad \text{and} \quad i_2 = \frac{Ir_1}{r_1 + r_2}$$

Example.—The total current passing in a circuit is 24 amperes. The circuit divides into two branches having resistances of 5 and 7 ohms respectively. What is the current in each branch?

Solution.—In this case $I = 24$, $r_1 = 5$ and $r_2 = 7$. Substituting these values in the above formulas we have,

$$i_1 = \frac{Ir_2}{r_1 + r_2} = \frac{24 \times 7}{5 + 7} = 14 \text{ amperes.}$$

and

$$i_2 = \frac{Ir_1}{r_1 + r_2} = \frac{24 \times 5}{5 + 7} = 10 \text{ amperes.}$$

Ans. { In 5 ohm branch, 14 amperes.
In 7 ohm branch, 10 amperes.

Joint Resistance of Divided Circuits. As a divided circuit offers two paths to the current, it follows that the joint resistance of the two branches will be less than the resistance of either branch alone. The ability of a circuit to conduct electricity is represented by its conductance, which is the reciprocal of resistance; and the conductance of a divided circuit is equal to the sum of the conductances of its parts.

For example, in Fig. 3, the conductance of the upper branch equals $\frac{1}{r_1}$ and that of the lower branch equals $\frac{1}{r_2}$. If R represents the joint resistance of the two parts then the joint conductance equals:

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} = \frac{r_1 + r_2}{r_1 r_2}$$

Having thus obtained the joint conductance, the joint resistance is found by taking the reciprocal of the conductance, that is,

$$R = \frac{r_1 r_2}{r_1 + r_2}$$

This formula may be stated as follows:

The joint resistance of a divided circuit is equal to the product of the two separate resistances divided by their sum.

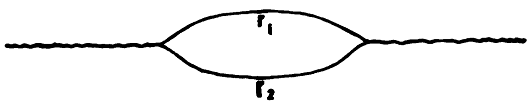


Fig. 3.

For example, suppose the resistance of each branch to be 2 ohms. The conductance of the circuit will be,

$$\frac{1}{R} = \frac{1}{2} + \frac{1}{2} = 1, \text{ and hence } R = 1 \text{ ohm.}$$

Also by the preceding formula,

$$R = \frac{2 \times 2}{2 + 2} = 1 \text{ ohm.}$$

The resistance of a divided circuit in which each branch has a resistance of 2 ohms is therefore 1 ohm.

Example.—The resistances of two separate conductors are 3 and 7 ohms respectively. What would be their joint resistance if connected in parallel?

Solution.—In this case $r_1 = 3$ and $r_2 = 7$, hence by the formula,

$$R = \frac{3 \times 7}{3 + 7} = 2.1 \text{ ohms.} \qquad \text{Ans. } 2.1 \text{ ohms.}$$

Suppose, as illustrated in Fig. 4, the conductors having resistances equal to r_1, r_2 and r_3 respectively, are connected in

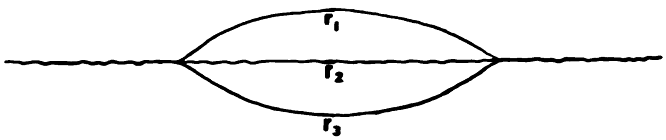


Fig. 4.

parallel. The joint total conductance will then be equal to,

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} = \frac{r_2 r_3 + r_1 r_3 + r_1 r_2}{r_1 r_2 r_3}$$

and as the joint resistance is the reciprocal of the joint conductance, the joint resistance R of the three branches is expressed by the formula,

$$R = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2}$$

Example.—What is the joint resistance when connected in parallel, of three wires whose respective resistances are 41, 52 and 29 ohms respectively?

Solution.—In this case $r_1 = 41$, $r_2 = 52$ and $r_3 = 29$. Hence, by the preceding formula,

$$R = \frac{41 \times 52 \times 29}{52 \times 29 + 41 \times 29 + 41 \times 52} = 12.8 + \text{ohms.}$$

Ans. 12.8 + ohms.

In general, for any number of conductors connected in parallel, the joint resistance is found by taking the reciprocal of the sum of the reciprocals of the separate resistances.

Example.—A circuit is made up of five wires connected in parallel, and their separate resistances are respectively 12, 21, 28, 8 and 42 ohms. What is the joint resistance?

Solution.—The sum of the conductances is:

$$\frac{1}{12}+\frac{1}{21}+\frac{1}{28}+\frac{1}{8}+\frac{1}{42}=\frac{53}{168}$$

Hence the joint resistance equals:

$$R=\frac{168}{53}=3.1+\text{ ohms.}$$ **Ans. 3.1 + ohms.**

If the resistance of each branch is known and also the potential difference between the points of union, then the current in each branch may be found by applying Ohm's law to each branch separately. For example, if this potential difference were 96 volts, and the separate resistances of the 4 branches were 8, 24, 3 and 48 ohms respectively, then the current in the respective branches would be 12, 4, 32 and 2 amperes respectively.

If the current in each branch is known and also the potential difference between the points of union, then the resistance of each branch may likewise be found from Ohm's law.

The following examples are given to illustrate the application of the preceding principles.

EXAMPLES FOR PRACTICE.

1. Two conductors having resistances of 71 and 19 ohms respectively are connected in parallel, and the total current passing in the circuit is 37 amperes. What current passes in the conductor whose resistance is 71 ohms? Ans. 7.8 + amperes.

2. What is the joint resistance of two wires connected in parallel if their separate resistances are 2 and 8 ohms respectively? Ans. 1.6 ohms.

3. What is the joint resistance of three wires when connected in parallel, whose separate resistances are 5, 7 and 9 ohms respectively? Ans. 2.2 + ohms.

4. Three wires, the respective resistances of which are 8, 10 and 20 ohms, are joined in parallel. What is their joint resistance? Ans. 3.6 + ohms.

5. Four wires are joined in parallel, and their separate resistances are 2, 4, 6 and 9 ohms respectively. What is the joint resistance of the conductor thus formed? Ans. .97 + ohm.

Battery Circuits. Fig. 5 illustrates a simple circuit having a single cell *C* connected in series with a resistance. This is the customary manner of representing a cell, the short, heavy line representing the zinc and the long light line representing the copper or carbon plate. In determining the amount of current which will flow in such a circuit, the total resistance of the circuit must be considered. This is made up of the external resistance *R* and the internal resistance *r*, or the resistance of the cell itself. If *E* represents the total E. M. F. of the cell, then the current *I* which will flow is expressed by the formula,

$$I = \frac{E}{R + r}$$

It has been shown that whenever a current passes through any resistance, there is always a certain *drop* or fall of potential. The total E. M. F. above referred to, expresses the total potential difference between the plates of the cell and is the E. M. F. of the cell on *open* circuit. When the current flows, however, there is a fall of potential or loss of voltage within the cell itself, and hence the E. M. F. of the cell on closed circuit is less than on open circuit. That is, if the voltage be measured when the cell is supplying current, it will be found to be less than when the voltage is measured on open circuit, or when the cell is supplying no current. The voltage on closed circuit is that available for the external circuit, and is therefore called the ***external*** or ***available*** voltage or E. M. F.

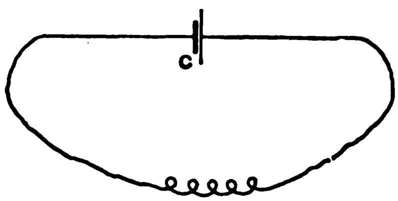


Fig. 5.

The external E. M. F. depends of course upon the strength of current the cell is supplying, and may be calculated as follows:

If the current passing is *I* and the resistance of the cell is *r*, then from Ohm's law the voltage lost in the cell equals $r\,I$. If *E* represents the total E. M. F. of the cell and E_1 the external E. M. F., then,

$$E_1 = E - r\,I$$

The E. M. F. of a cell is understood to be the total E. M. F. unless otherwise stated.

When two or more cells are interconnected they are said to form a *battery*.

Fig. 6 illustrates three cells connected in series with each other and with the external circuit. That is, the positive terminal of one cell is connected to the negative of the next, and the positive of that cell to the negative of the adjacent, etc. By this method of connecting, the E. M. F. of each cell is added to that of the others, so that the total E. M. F. of the circuit is three times that of a single cell. If one of the cells were connected so that its E. M. F. opposed that of the other two, it would offset the E. M. F. of one of the cells and the resultant E. M. F. would be that of a single cell. The connecting of cells in series as in

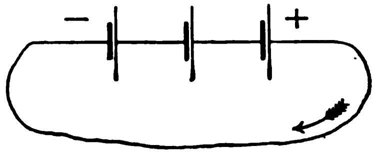


Fig. 6.

Fig. 6 not only increases the E. M. F. of the circuit but also increases the internal resistance, the resistance of each cell being added to that of the others. If E equals the E. M. F. of each cell, r the internal resistance of each and R the external resistance, then the current that will flow is expressed by the formula,

$$I = \frac{3E}{R + 3r}$$

or for n cells connected in series the formula for current is,

$$I = \frac{nE}{R + nr}$$

Fig. 7 illustrates two cells connected in parallel, and supplying current to an external circuit. Here the two positive terminals are connected with each other and also the two negative. The E. M. F. supplied to the circuit is equal to that of a single cell only. In

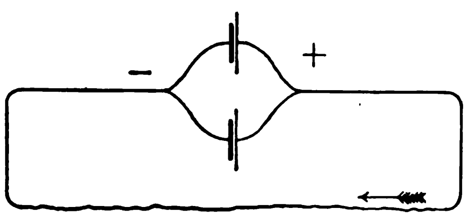


Fig. 7.

fact connecting cells in parallel, is equivalent to enlarging the plates, and the only effect is to decrease the internal resistance. It is evident that coupling two cells in parallel affords two paths for the current and so decreases the resistance of the two cells to one-half that of a single cell. The formula expressing the current that would flow in the external circuit with two cells in parallel is therefore,

$$I = \frac{E}{R + \frac{r}{2}}$$

or for n cells connected in parallel, the formula for current is,

$$I = \frac{E}{R + \frac{r}{n}}$$

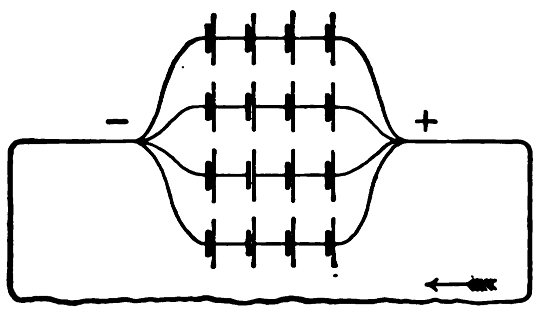


Fig. 8.

Fig. 8 represents a combination of the series and parallel method of connecting and represents four files of cells joined in parallel and each file having four cells connected in series. The E. M. F. of each file and consequently of the circuit is $4\,E$. The resistance of each file is $4\,r$ and that of all the files $\frac{4\,r}{4}$. Hence, the formula for current is,

$$I = \frac{4\,E}{R + \frac{4r}{4}}$$

If there were n files connected in parallel and m cells were connected in series in each file, the formula expressing the current in the external circuit would be,

$$I = \frac{m E}{R + \frac{m r}{n}}$$

where E is the E. M. F. of each cell, R the external resistance, and r the internal resistance of each cell.

The most advantageous method of connecting cells depends upon the results desired, the resistance of the cell and the external resistance. Suppose it is desired to pass a current through an external resistance of 2 ohms, and that Daniell's cells are to be used each having an E. M. F. of 1 volt and an internal resistance of 3 ohms.

With one cell only in circuit, the current will be,

$$\frac{E}{R + r} = \frac{1}{2 + 3} = .2 \text{ ampere},$$

and with 5 cells all in series the current will be,

$$\frac{5 E}{R + 5 r} = \frac{5}{2 + 15} = .3 \text{ ampere (approx.)}.$$

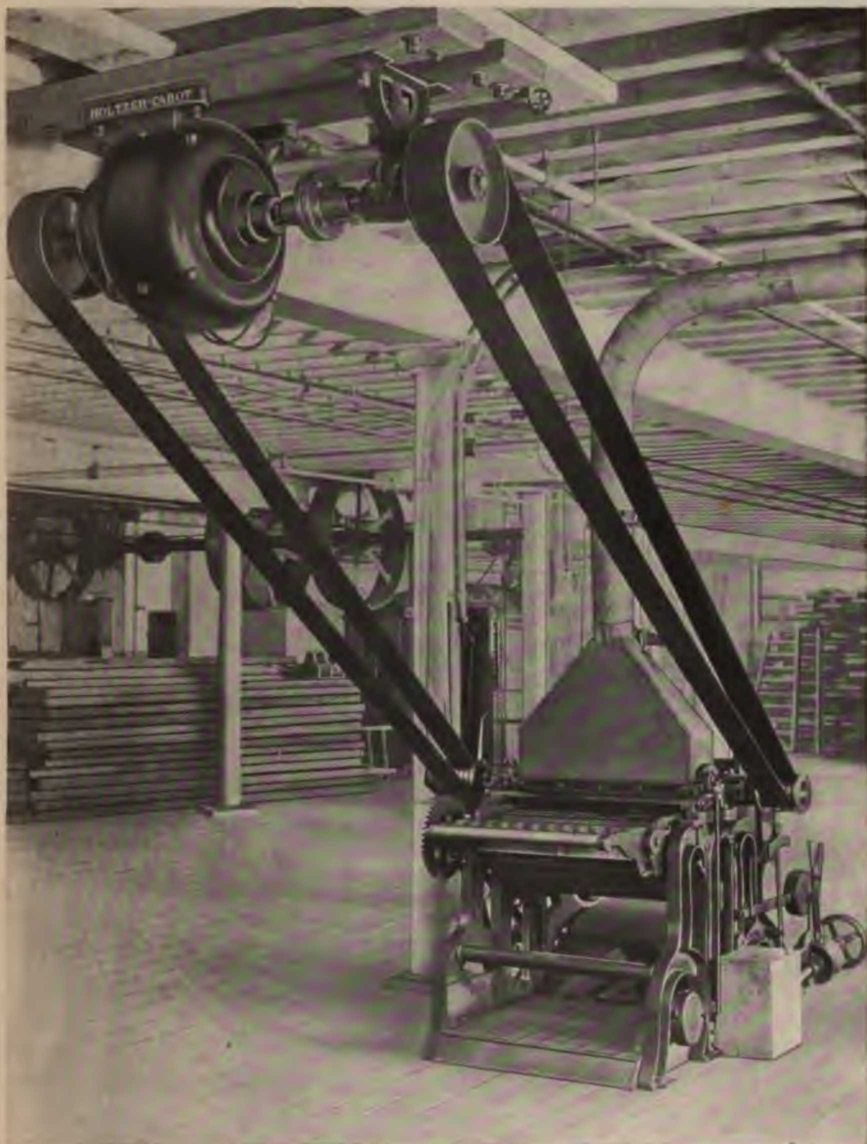
Therefore with 5 cells in series the current is only .1 ampere greater than with a single cell, and with 100 cells in series the current is only,

$$\frac{100 E}{R + 100 r} = \frac{100}{2 + 300} = .33 \text{ ampere}.$$

Hence with a comparatively low external resistance, there is but little gain in current strength by the addition of cells in series. This is due to the fact that, although the E. M. F. is increased 1 volt by each cell, the resistance is increased by 3 ohms.

Now suppose 5 Daniell cells to be connected in parallel with the external circuit of 2 ohms. The E. M. F. of the circuit will then be that of a single cell and the current will be,

$$\frac{E}{R + \frac{r}{5}} = \frac{1}{2 + \frac{3}{5}} = .4 \text{ ampere (nearly)},$$



DUST-PROOF MOTOR BELTED TO LAG BED PLANER.

Holtzer-Cabot Electric Company.

and with 100 cells connected in parallel the current will be,

$$\frac{E}{R + \frac{r}{100}} = \frac{1}{2 + \frac{3}{100}} = .5 \text{ ampere (nearly).}$$

A larger current is therefore obtained in this case by connecting the cells in parallel than by connecting them in series.

With a large external resistance on the other hand, a larger current is obtained by connecting the cells in series. For example, suppose the external resistance to be 500 ohms. One cell will then give a current of .00198 + ampere, and 5 cells in series will give about .0097 ampere, whereas 100 cells will give .125 ampere. With 5 cells connected in parallel the current will be .00199 + ampere, and with 100 cells the current will amount to approximately .002 ampere. With an external resistance of 500 ohms, there is practically no advantage in connecting the cells in parallel. The only effect of the latter method is to decrease the internal resistance which is almost negligible in comparison with the external resistance.

It may be shown mathematically that for a given external resistance and a given number of cells, the largest current is obtained when the internal resistance is *equal* to the external resistance. In order to obtain this result the values of m and n in the formula on page 30, should be so chosen that $\frac{m r}{n}$ equals R. This arrangement, although giving the largest current strength, is not the most economical. With the internal resistance equal to the external resistance there is just as much energy used up in the battery itself as is expended usefully in the external circuit.

In order to obtain the most economical arrangement, the internal resistance should be made as small as possible, that is, all the cells should be connected in parallel. The loss of power in the battery is then the smallest amount possible.

In order to obtain the quickest action of the current the cel[illegible] should be connected in series. When the external circuit possesses considerable self-induction, as is the case when electr[illegible] [illegible]re connected in the circuit, the action of the curren[illegible]

This retardation may be decreased by having a high internal resistance, which is obtained by connecting the cells in series.

Example.—Sixteen cells, each having an internal resistance of .1 ohm are to be connected with a circuit whose resistance is .4 ohm. How should the cells be connected to obtain the greatest current?

Solution.—Here the external resistance R, equals .4 ohm and the resistance r of each cell equals .1 ohm. For maximum current,

$$\frac{m\,r}{n} = R, \text{ or } \frac{.1\,m}{n} = .4$$

Therefore, $$m = 4\,n$$

and as $m\,n = 16$, the only values of m and n which will be true for both of these equations are $m = 8$ and $n = 2$. Hence there must be 2 files of cells, with 8 cells in series in each file.

Ans. 2 files, 8 cells in each.

Example.—The external resistance in a circuit is 4 ohms. The cells used each have an E. M. F. of 1.2 volts and an internal resistance of 3.8 ohms. If 20 cells were used, which method of connecting would supply the larger current,—5 files with 4 cells in series, or 4 files with 5 cells in series?

1st Solution.—Applying the formula on page 30, we have $R = 4$, $E = 1.2$, $r = 3.8$ and with 5 files and 4 in series, $m = 4$ and $n = 5$. Hence, the current is,

$$\frac{m\,E}{R + \frac{m\,r}{n}} = \frac{4 \times 1.2}{4 + \frac{4 \times 3.8}{5}} = .681 + \text{ampere.}$$

With 4 files and 5 cells in series, $m = 5$ and $n = 4$. Hence the current is,

$$\frac{5 \times 1.2}{4 + \frac{5 \times 3.8}{4}} = .685 + \text{ampere.}$$

The larger current is therefore supplied by having 4 files with 5 cells in series. Ans. 4 files, with 5 cells in series.

2nd Solution.—The maximum current is supplied when the internal resistance equals the external resistance or when

$$\frac{m\,r}{n} = R.$$

With 5 files and 4 cells in series,

$$\frac{m\,r}{n} = \frac{4 \times 3.8}{5} = 3.04 \text{ ohms},$$

and with 4 files and 5 cells in series,

$$\frac{m\,r}{n} = \frac{5 \times 3.8}{4} = 4.75 \text{ ohms}.$$

The latter value is nearer to 4 ohms, which is the external resistance, than is 3.04, hence the larger current will be supplied with 4 files and 5 cells in series. Ans. 4 files, with 5 cells in series.

Example.—It is desired to pass a current of .025 ampere through an external resistance of 921 ohms. The cells are to be connected in series and each has an E. M. F. of .8 volt and an internal resistance of 1.3 ohms. What number of cells must be used?

Solution.—From page 28, the general formula for cells in series is,

$$I = \frac{n E}{R + n\,r}$$

and in this case $I = .025$, $E = .8$, $R = 921$ and $r = 1.3$. Substituting these values gives,

$$.025 = \frac{n\,.8}{921 + n\,1.3}$$

Multiplying by $921 + 1.3\,n$ gives

$$23.025 + .0325\,n = .8\,n$$

Transposing $.0325\,n$ gives

$$.8\,n - .0325\,n = 23.025$$

or

$$.7675\,n = 23.025$$

hence,

$$n = 30$$

Ans. 30 cells.

EXAMPLES FOR PRACTICE.

1. Ten cells in series have an E. M. F. of 1 volt each and an internal resistance of .2 ohm. The external resistance is 3 ohms. What is the current? Ans. 2 amperes.

2. Six cells, each of which has an E. M. F. of 1.2 volts and a resistance of 2 ohms, are connected in parallel. With an external resistance of 10 ohms, what is the current? Ans. .116 + ampere.

3. What is the current supplied by the same cells if joined in series and the external resistance is 20 ohms?

Ans. .225 amperes.

4. A single cell whose E. M. F. on open circuit is 1.41 volts and whose internal resistance is .5 ohm is supplying a current of .3 ampere. What is the available E. M. F. of the cell?

Ans. 1.26 volts.

5. What would be the available E. M. F. with 8 of the cells referred to in example 4, when connected in series and supplying the same current? Ans. 10.08 volts.

6. Eight Daniell cells (E. M. F. = 1.05, resistance = 2.5 ohms each) are joined in series. Three wires *A*, *B* and *C* of 9, 36 and 72 ohms resistance respectively are arranged to be connected to the poles of the battery. Find the current when each wire is inserted separately, and when all three wires are connected in parallel.

Ans. Through *A*, .29 ampere nearly; through *B*, .15 ampere; through *C*, .091 + ampere; and through all three, .31 + ampere.

7. A battery of 28 Bunsen cells (E. M. F. = 1.8, resistance = .1 ohm each) are to supply current to a circuit having an external resistance of 30 ohms. Find the current (*a*) when all the cells are joined in series, (*b*) when all the cells are in parallel, (*c*) when there are 2 files each having 14 cells in series, (*d*) when there are 7 files each having 4 cells in series.

Ans. (*a*) 1.53 +; (*b*) .06 nearly; (*c*) .82 +; (*d*) .23 + ampere.

QUANTITY, ENERGY AND POWER.

Quantity. The strength of a current is determined by the amount of electricity which passes any cross section of the conductor in a second; that is, current strength expresses the ***rate*** at which electricity is conducted. The *quantity* of electricity conveyed evidently depends upon the current strength and the time the current continues.

The Coulomb. The coulomb is the unit of quantity and is equal to the amount of electricity which passes any cross-section of the conductor in one second when the current strength is one ampere. If a current of one ampere flows for two seconds, the quantity of electricity delivered is two coulombs, and if two amperes flow for one second the quantity is also two coulombs. With a current of four amperes flowing for three seconds, the quantity delivered is 12 coulombs. The quantity of electricity in coulombs is therefore equal to the current strength in amperes multiplied by the time in seconds, or

$$Q = I \times t$$

where Q is the quantity in coulombs, I the current in amperes and t the time in seconds.

The coulomb is also called the *ampere-second*. The quantity of electricity delivered in one hour when the current is one ampere is called one *ampere-hour*. The ampere-hour is equal to 3,600 coulombs, as it is equal to one ampere for 3,600 seconds.

From the formula $Q = It$, it follows that

$$I = \frac{Q}{t} \text{ and } t = \frac{Q}{I}$$

Example.—A current of 18 amperes flows through a circuit for $2\frac{1}{4}$ hours. What quantity of electricity is delivered?

Solution.—Reducing $2\frac{1}{4}$ hours to seconds gives 8,100 seconds, and $8{,}100 \times 18 = 145{,}800$. Ans. 145,800 coulombs.

Example.—What is the strength of current when $1\frac{1}{2}$ ampere-hours pass in a circuit in 89 seconds?

Solution.—One and one-half ampere-hours equal 5,400 coulombs and as current strength is expressed by quantity divided by time, the current is $5{,}400 \div 89 = 60.+$ amperes.

Ans. 60. + amperes.

EXAMPLES FOR PRACTICE.

1. How many coulombs are delivered in 9 minutes, when the current is $17\frac{1}{2}$ amperes? Ans. 9,450 coulombs.

2. What is the current when 480 coulombs are delivered per minute? Ans. 8 amp

3. In what time will 72,000 coulombs be delivered when the current is 80 amperes? Ans. 15 minutes.

4. How many ampere-hours pass in a circuit in $2\frac{3}{4}$ hours when the current is 22 amperes? Ans. 60.5 ampere-hours.

Energy. Whenever a current flows, a certain amount of energy is expended, and this may be transformed into heat, or mechanical work, or may produce chemical changes. The unit of mechanical energy is the amount of work performed in raising a mass of one pound through a distance of one foot, and is called the foot-pound. The work done in raising any mass through any height, is found by multiplying the number of pounds in that mass by the number of feet through which it is lifted. Electrical work may be determined in a corresponding manner by the amount of electricity transferred through a difference of potential.

The Joule. The joule is the unit of electrical energy, and is the work performed in transferring one coulomb through a difference of potential of one volt. That is, the unit of electrical energy is equal to the work performed in transferring a unit quantity of electricity through a unit difference of potential. It is evident that if 2 coulombs pass in a circuit and the difference of potential is one volt, the energy expended is 2 joules. Likewise if 1 coulomb passes and the potential difference is 2 volts, then the energy expended is also 2 joules. Therefore, to find the number of joules expended in a circuit, multiply the quantity of electricity by the potential difference through which it is transferred. This is expressed by the formula,

$$W = Q\ E, \text{ or } W = I\ E\ t,$$

where W is the work in joules, Q the quantity in coulombs, E the potential difference in volts, I the current in amperes and t the time in seconds.

By Ohm's law $E = R\ I$ and by substituting this value of E in the equation for energy, we obtain the formula,

$$W = I^2\ R\ t,$$

which may be used when the current, resistance, and time are known, R being the resistance in ohms.

Example.—With a potential difference of 97 volts and a current of 14 amperes, what energy is expended in 20 minutes?

Solution.—Work is expressed by the product of the quantity and potential difference. The time in seconds equals $20 \times 60 = 1200$, and the work $W = 14 \times 1200 \times 97 = 1{,}629{,}600$ joules.

Ans. 1,629,600 joules.

Example.—The resistance of a circuit is .9 ohm, and the current is 25 amperes. What energy is expended in half an hour?

Solution.—Substituting these values of resistance, current and time in the formula $W = I^2 R t$, we have, $W = 25^2 \times .9 \times 30 \times 60 = 1{,}012{,}500$ joules. Ans. 1,012,500 joules.

Power. Power is the *rate* of doing work, and expresses the amount of work done in a certain time. The horse-power is the unit of mechanical energy, and is equal to 33,000 foot-pounds per minute or 550 foot-pounds per second. A certain amount of work may be done in one hour or two hours, and in stating the work done to be so many foot-pounds or so many joules, the rate at which the work is done is not expressed. Power on the other hand, includes the rate of working.

It is evident that if it is known that a certain amount of work is done in a certain time, the rate at which the work is done, or the power, may be obtained by dividing the work by the time, giving the work done per unit of time.

The Watt. The electrical unit of power is the watt, and is equal to one joule per second, that is, when one joule of work is expended in one second, the power is one watt. If the number of joules expended in a certain time is known, then the power in watts is obtained by dividing the number of joules by the time in seconds. The formulas for the work done in joules as given on the preceding pages are,

$$W = I E t, \text{ and } W = I^2 R t.$$

By dividing each of these by the time t, we obtain the corresponding formulas for power as follows:

$P = I E$, and $P = I^2 R$, where P is the power in watts, I the current in amperes, E the potential difference in volts, and R the resistance in ohms.

The power is obtained therefore, by multiplying the current by the voltage, or by multiplying the square of the current by the resistance.

The watt is sometimes called the *volt-ampere*.

For large units the *kilowatt* is used, and this is equal to 1,000 watts. The common abbreviation for kilowatt is K. W. The *kilowatt-hour* is a unit of energy, and is the energy expended in one hour when the power is one kilowatt.

EXAMPLES FOR PRACTICE.

1. A current of 40 amperes is supplied to a circuit and the voltage is 110. What is the power in watts? Ans. 4400 watts.

2. What is the power in kilowatts supplied to a number of incandescent lamps when the current is 84 amperes and the voltage of the circuit 97? Ans. 8.1+ kilowatts.

3. A circuit has a resistance of 50 ohms and the current is 12 amperes. What power is expended in the circuit?

Ans. 7.2 K. W.

4. The voltage of an incandescent lamp circuit is 220 volts, and the resistance 2 ohms. What power is expended in the circuit? Ans. 24.2 K. W.

NOTE.--First find current by Ohm's law.

Equivalence of Electrical Energy in Heat Units. Whenever there is any resistance to the flow of a current there is always a certain amount of electrical energy transformed into heat. The current in passing through such resistance expends a certain amount of energy in overcoming the resistance, and this energy is dissipated as heat. The entire electrical energy of a circuit may be transformed into heat, as in a lamp circuit, or only part of the energy may appear as heat, the remainder being transformed into mechanical or chemical work. The energy which appears as heat raises the temperature of the circuit to an amount depending upon its radiating surface, and the temperature of the surrounding medium.

When the resistance of a circuit and the current are known, the electrical energy expended may be calculated by finding the product of the square of the current, the resistance, and the time, as by the formula at the foot of page 36. All this energy is transformed into heat. Other work may be done by the current, as would be the case if an electric motor were connected to the circuit, but this requires additional energy to that which is dissipated as heat. The formula referred to gives only the energy lost as heat, which is the total energy when no other work is done.

This formula, which gives the energy in joules, is in accordance with Joule's law, which is as follows:

The number of heat units developed in a conductor is proportional to its resistance, to the square of the current, and to the time the current lasts.

As we have seen, the unit of electrical energy is the joule. The common unit of heat is the calorie, which is the amount of heat necessary to raise the temperature of 1 gram of water through 1 degree Centigrade. By careful investigations it has been found that the joule is equivalent to .24 of a calorie; that is, one joule of electrical energy when transformed into heat is equal to .24 calorie. Electrical energy may therefore be expressed in heat units by multiplying the number of joules by .24; that is,

$$U = I^2 \times R \times t \times .24$$

where U is the heat in calories.

As one joule is equivalent to .24 calorie, it follows that one calorie is equivalent to 4.2 joules approximately.

EXAMPLES FOR PRACTICE.

1. How many calories will be developed by a current of 30 amperes flowing through a resistance of 12 ohms for 10 seconds?

Ans. 25,920 calories.

2. What amount of heat will a current of 20 amperes develop if it flows through a resistance of 80 ohms for 2 seconds?

Ans. 15,360 calories.

Equivalent of Electrical Energy in Mechanical Units. The common unit of mechanical energy is the foot-pound, and from experiment it has been found that one joule is equivalent to .7373 foot-pound; that is, the same amount of heat will be developed by one joule as by .7373 foot-pound of work.

As one horse-power is equal to 550 foot-pounds per second, it follows that this rate of working is equivalent to

$$\frac{550}{.7373} = 746 \text{ joules per second (approx.).}$$

Hence one horse-power is equivalent to 746 watts. Therefore to find the equivalent of mechanical power in electrical power multiply the horse-power by 746, and to find the equivalent of electrical power in mechanical power divide the number of watts by 746.

EXAMPLES FOR PRACTICE.

1. A power of 287 watts is equivalent to how many horse-power? Ans. .38 + H. P.

2. The voltage applied to a circuit is 500 and the current is 196 amperes. What is the equivalent horse-power of the circuit? Ans. 131 + H. P.

3. What is the equivalent of 43 H. P. in kilowatts? Ans. 32 + K. W.

4. How many horse-power approximately are equivalent to one kilowatt? Ans. $1\frac{1}{3}$ H. P.

THE SUPPLY OF ELECTRICAL ENERGY.

Electrical energy is now made use of on such a large scale for lighting, power, heating, etc., that it is generated or produced by machines of great capacity. The dynamo is used for this purpose and machines having a capacity of several thousand kilowatts are now common.

Central Stations. Large central stations or power houses are built at convenient places and here are collected the generating, controlling and measuring apparatus. Usually steam engines or turbines are used to drive the dynamos, and from the latter, large copper mains conduct the current to the switchboard located within the station. Here are assembled all the regulating devices, instruments, and switches for the control of the system. From the switchboard conducting mains run out to various distant points, where the energy is to be used, to the receiving apparatus, such as electric motors, lamps, heating devices, etc. A complete system is therefore made up of three sub-divisions — the generating plant, the conducting mains, and the receiving apparatus.

Isolated Plants. Besides large central stations which occupy one or more entire buildings and which are usually built and designed especially for such purpose, there are the comparatively small and simple plants called isolated power plants. They are purely local systems and supply energy to a single building, or to buildings in the immediate vicinity. The generating apparatus in this case is usually located in the basement of the building.

Large hotels and office buildings are frequently provided with individual generating plants.

Losses in Energy. In operating an electrical machine there is always some loss in energy, that is, the machine does not give out an amount of energy equivalent to the amount it receives. Besides ordinary mechanical losses there is in addition the electrical loss, which always occurs when a current flows through any resistance. This loss as previously explained, is equal to the square of the current multiplied by the resistance.

The ratio of the amount of energy which a machine gives out, to the amount which it receives is called the **commercial efficiency** of the machine. For example, if the commercial efficiency of a dynamo is stated to be 80%, then 20% of the energy given to the dynamo is lost, partly in overcoming friction and partly in electrical losses.

Where electricity is transmitted some distance by means of conducting mains, there takes place a loss in the line due to heating, which is frequently as much as 10%. Also at the receiving station, if the electrical energy is converted into mechanical by means of an electric motor, there will be a further loss.

Illustrative Example. For example, suppose it is desired to ascertain the losses in a system which comprises a generator, conducting mains and an electric motor. Suppose the efficiency of the generator is 92% and that 1000 horse-power are imparted to it by the driving engine. The output of the dynamo will be $.92 \times 1000$, or 920 horse-power, and this is equivalent to 920×746, or 686,320 watts. The energy lost in the dynamo will be 80×746, or 59,680 watts. We will assume the voltage of the dynamo and the circuit to be 1000, and as the power in watts is equal to the product of the voltage and current, the current must be $686{,}320 \div 1000$, or 686 amperes approximately.

Now suppose the resistance of the conducting mains is equal to .11 ohms. Knowing the current in the mains and the resistance, the loss therein is obtained by applying the formula $I^2 R$ giving $686^2 \times .11$, or 51,765 watts. The energy available at the receiving end of the line will therefore be $686{,}320 - 51{,}765$, or 634,555 watts.

The remaining loss to be considered is that in the electric motor. Assuming the efficiency of the motor to be 90%, the power lost therein will be .10 × 634,555, or 63,455 watts. The output of the motor is therefore equivalent to 634,555 — 63,455, or 571,100 watts. This in mechanical units is equal to 571,100 ÷ 746, or 765 horse-power approximately.

Hence from an input of 1,000 horse-power at the generating station, the work the motor is capable of performing at the receiving station is 765 horse-power. The efficiency of the entire system under the assumed conditions is therefore 765 ÷ 1,000, or 76.5 %.

Among the great variety of generating machines, systems of distribution and auxiliary devices, each has its particular advantage for special conditions, and the selection of the type of machine and system of distribution depends almost entirely upon the special circumstances. For example, a low voltage system is best adapted for isolated plants, whereas for the transmission of power long distances very high voltages are used. The various types of machines, systems, etc., with their special advantages and disadvantages will be fully considered in the following Instruction Papers.

Seven 5000 H. P. Westinghouse Generator at Niagara Falls Power Co.

ELECTRICAL MEASUREMENTS.

ABSOLUTE AND PRACTICAL UNITS.

Fundamental Units. All physical quantities such as volume, velocity, force, etc., are derived from, and can be expressed in terms of the three fundamental quantities: **length, mass**, and **time.** Each of these quantities is independent of the other, and can only be measured ir terms of its own units.

The system of units in almost universal use by engineers and upon which the electrical units are based, is the **absolute** or **Centimetre-Gramme-Second** system, which is usually abbreviated to the **C. G. S.** system. The fundamental units in this system are:—

The **Centimetre** as a unit of **length**;

The **Gramme** as a unit of **mass**;

The **Second** as a unit of **time.**

The **Foot-Pound-Second** system is also used to some extent, the *foot*, *pound*, and *second* being the units of *length*, *mass*, and *time* respectively.

Derived Units. From the three fundamental units length, L, mass, M, and time, T, are derived all other physical quantities. For example, the area of a rectangular surface is obtained by multiplying the length by the width, or $S = L \times L = L^2$. It is therefore evident that the only unit entering into the measurement of surface is *length*, and that surface is measured by the product of two lengths, or L^2. Similarly, volume is measured by the product of three lengths, or L^3. Velocity which is the rate of motion, or space covered per unit of time, is expressed by $\frac{length}{time}$, or $\frac{L}{T} = L\,T^{-1}$. Hence the only quantities entering into the measurement of velocity are length and time, that is, length and time are the dimensions of velocity. In a similar manner it

SYMBOLS OF PHYSICAL QUANTITIES.

Recommended by the Committee on Notation of the Chamber of Delegates of the International Electrical Congress of 1893.

With the names added in italics of the practical magnetic units provisionally adopted by the American Institute of Electrical Engineers.

Physical Quantities.	Symbols.	Defining Equations.	Dimensions of the Physical Quantities.	Names of the C. G. S. Units.	Practical Units.
Fundamental.					
Length	L, l	....	L	Centimetre.	Metre.
Mass	M	....	M	Mass of one gramme.	Mass of a kilogramme.
Time	T, t	....	T	Second.	Minute; hour.
Geometric.					
Surface	S, s	$S = LL$	L^2	Square centimetre.	Square metre.
Volume	V	$V = LLL$	L^3	Cubic centimetre.	Cubic metre.
Angle	α, β	$\alpha = \frac{\text{arc}}{\text{radius}}$	A number.	Radian.	Degree; minute; second; grade.
Mechanical.					
Velocity	v	$v = \frac{L}{T}$	LT^{-1}	Centimetre per second.	Metre per second.
Angular Velocity	ω	$\omega = \frac{v}{L}$	T^{-1}	Radian per second.	Revolutions (turns) per minute.
Acceleration	a	$a = \frac{v}{T}$	LT^{-2}	Centimetre per second per second.	Metre per second per second.
Force	F, f	$F = Ma$	LMT^{-2}	Dyne.	Gramme; kilogramme.
Work	W	$W = FL$	L^2MT^{-2}	Erg.	Kilogrammetre.
Power	P	$P = \frac{W}{T}$	L^2MT^{-3}	Erg per second.	Kilogrammetre per second.
Pressure	p	$p = \frac{F}{S}$	$L^{-1}MT^{-2}$	Dyne per square centimetre.	Kilogram per square centimetre.
Moment of Inertia	K	$K = ML^2$	L^2M	Gramme-mass-centimetre-squared.	
Magnetic.					
Strength of Pole	m	$F = \frac{m^2}{L^2}$	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-1}$		
Magnetic Moment	$\mathfrak{M}$	$\mathfrak{M} = ml$	$L^{\frac{5}{2}}M^{\frac{1}{2}}T^{-1}$		
Intensity of Magnetization	$\mathfrak{I}$	$\mathfrak{I} = \frac{\mathfrak{M}}{V}$	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$		
Field Intensity	$\mathcal{H}$	$\mathcal{H} = \frac{F}{m}$	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	*Gauss.*	*Gauss.*
Flux of (Magnetic) Force	Φ	$\Phi = \mathcal{H}S$	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-1}$	*Weber.*	*Weber.*
Magnetic Induction	$\mathcal{B}$	$\mathcal{B} = \mu\mathcal{H}$	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	*Gauss.*	*Gauss.*
Magnetizing Force†	$\mathcal{H}$	$\mathcal{H} = \frac{4\pi NI}{L}$	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	*Gauss.*	*Gauss.*
Magnetomotive Force	$\mathcal{F}$	$\mathcal{F} = 4\pi NI$	$L^{\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	*Gilbert.*	*Gilbert*; 1 *Gilbert* = 0.7958 ampère-turns (a-t).
Reluctance (Magnetic Resistance)	$\mathcal{R}$	$\mathcal{R} = \nu\frac{L}{S}$	L^{-1}	*Oersted.*	*Oersted.*
(Magnetic) Permeability	μ	$\mu = \frac{\mathcal{B}}{\mathcal{H}}$	A number.		
(Magnetic) Susceptibility	κ	$\kappa = \frac{\mathfrak{I}}{\mathcal{H}}$	A number.		
Reluctivity (Specific Magnetic Resistance)	ν	$\nu = \frac{1}{\mu}$	A number.		
Electromagnetic.					
Resistance	R, r	$R = \frac{E}{I}$	LT^{-1}	....	Ohm.
Electromotive Force	E, e	$E = RI$	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-2}$	....	Volt.
Difference of Potential	U, u	$U = RI$	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-2}$	....	Volt.
Intensity of Current	I, i	$I = \frac{E}{R}$	$L^{\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	....	Ampère.
Quantity of Electricity	Q, q	$Q = IT$	$L^{\frac{1}{2}}M^{\frac{1}{2}}$	....	Coulomb; ampère-hour
Capacity	C, c	$C = \frac{Q}{E}$	$L^{-1}T^2$	....	Farad.
Electric Energy	W	$W = EIT$	L^2MT^{-2}	....	Joule; watt-hour.
Electric Power	P	$P = EI$	L^2MT^{-3}	....	Watt; kilowatt.
Resistivity (Specific Resistance)	ρ	$\rho = \frac{RS}{L}$	L^2T^{-1}	....	Ohm-centimetre.
Conductance	G, g	$G = \frac{1}{R}$	$L^{-1}T$	....	Mho.
Conductivity (Specific Conductance)	γ	$\gamma = \frac{1}{\rho}$	$L^{-2}T$		
Coefficient of Induction (Inductance)	L, l	$L = \frac{\Phi}{I}$	L	....	Henry.

† N is the number of windings, and L the length of the solenoid generating the magnetizing force.

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may be shown that every physical quantity such as force, work, resistance, etc., may be expressed in terms of one or more of the three fundamental units.

A table of *Symbols of Physical Quantities* is given on page 4. The first column gives the names of the physical quantities, the fundamental, geometrical, mechanical, etc. The second column gives the symbols for each of the physical quantities. In the third column appears what are termed the defining equations, that is, the equations which express the relation between the different quantities. The dimensions of the physical quantities are given in the fourth column. For example, the dimensions of velocity, as we have seen, are $L\,T^{-1}$. The fifth column contains the names of the absolute or *C. G. S.* units, and the sixth those of the practical units.

Definitions of the absolute and practical electrical units are given on the following pages, and are arranged so that they may be easily referred to.

The *C. G. S.* units upon which the electrical units depend are as follows:

Surface. — The unit of surface is the **square centimetre.**

Volume. — The unit of volume is the **cubic centimetre.**

Velocity. — The unit of velocity is the velocity of a body which moves through unit distance in unit time, or one **centimetre per second.**

Acceleration. — The unit of acceleration is that acceleration which imparts unit velocity to a body in unit time, or one **centimetre per second per second.**

Force.—The unit of force is that force which, acting for one second on a mass of one gramme, gives to it a velocity of one centimetre per second. This unit is called one **dyne.**

Work. — The unit of work is the work done in overcoming a force of one dyne through a distance of one centimetre. This unit is called one **erg.**

Energy. — Since the energy of a body is measured by its ability to do work, the unit of energy is also the **erg.**

Power. — The unit of power is the activity when one unit work is done in a unit time, or one **erg per second.**

ABSOLUTE ELECTRICAL UNITS.

The magnetic units are as follows:

Strength of Pole. — The unit magnetic pole is one of such a strength that when placed at a distance of one centimetre (in air) from a similar pole of equal strength, it is repelled with a force of one dyne.

Magnetic Potential. — Magnetic potential is measured by the work done on unit pole in moving it against the magnetic forces.

Difference of Magnetic Potential. — The unit difference of magnetic potential exists between two points, when it requires the expenditure of one *erg* of work to bring a unit magnetic pole from one point to the other against the magnetic forces.

Field Intensity. — The unit field intensity is that intensity of field which acts on a unit pole with a force of one dyne. This unit is called one **gauss** and is equal to one line of force per square centimetre.

Magnetic Flux. — The unit of magnetic flux is that amount of magnetism which passes through unit area of magnetic field when the field intensity is unity. This unit is one magnetic line and is called one **weber.**

Magnetomotive Force. — This is measured in the same units as difference of magnetic potential. This unit is called one **gilbert.**

Reluctance. — The unit of reluctance is that reluctance when unit magnetomotive force generates in it a flux of one magnetic line. This unit is called one **oersted,** and is the reluctance of a cubic centimetre of air.

From the preceding magnetic units are derived the following absolute **electromagnetic** units:

Intensity of Current. — A current of unit intensity is such that when one centimetre length of its circuit is bent into an arc of one centimetre radius, it exerts a force of one dyne on a unit magnetic pole placed at its center.

Electromotive Force. — The unit difference of electromotive force or potential exists between two points when it requires the expenditure of one *erg* of work to bring a unit of positive electricity from one point to the other against the electric force. A unit electromotive force is generated by cutting one magnetic line per second.

Resistance. — The unit of resistance is such a resistance that unit difference of potential existing between its terminals, causes a current of unit intensity to flow through it.

Quantity of Electricity.—The unit quantity of electricity is that quantity which is conveyed by unit current in one second.

Capacity. — The unit capacity is such that unit quantity of electricity charges it to unit potential difference.

Inductance. — The unit inductance is such that unit electromotive force is induced by the variation of the current at the rate of one unit current per second.

PRACTICAL ELECTRICAL UNITS.

In practical work the resistance and electromotive forces commonly met with are usually so large that if the absolute electromagnetic *C. G. S.* units were used, the resulting numerical values would be inconvenient. On the other hand, capacities are generally so small that their numerical values in *C. G. S.* units would be very small fractions. For practical use therefore, certain multiples of the *C. G. S.* units of resistance and electromotive force, and a submultiple of that of capacity have been chosen.

The following are the **practical** units:

Resistance. — The **ohm** = 10^9 (or 1,000,000,000) absolute units of resistance. The **International Ohm,** which is equal to one true ohm as nearly as known, is the resistance of a uniform column of mercury 106.3 centimetres long and 14.4521 grammes in mass, at the temperature of melting ice. The **megohm** is a resistance of one million ohms.

Current. — The **ampere** = 10^{-1} (or one-tenth) absolute units. This unit is practically represented by the unvarying current which, when passed through a solution of silver nitrate in water, deposits silver at the rate of .001118 gramme per second.

Electromotive Force. — The **volt** = 10^8 (or 100,000,000) absolute units, and is that E. M. F. which applied to one ohm will produce in it a current of one ampere. The volt is equal to $\frac{1000}{1434}$ of the E. M. F. of a Clark standard cell at 15° C.

Quantity. — The **coulomb** $= 10^{-1}$ (or one-tenth) absolute units of quantity; being the quantity of electricity conveyed by one ampere in one second. The **ampere-hour** is the quantity of electricity conveyed by one ampere in one hour.

Capacity. — The **farad** $= 10^{-9}$ (or one one-thousand-millionth) absolute unit of capacity; and is the capacity of a condenser which is charged to a potential of one volt by one coulomb of electricity. The **microfarad** is one millionth of a farad and $= 10^{-15}$ absolute units.

Work. — The **joule** $= 10^{7}$ absolute units of work (or 10,000,000 ergs) and is represented by the energy expended in one second by one ampere passing through a resistance of one ohm. The **watt-hour** is the energy expended in one hour when the activity, or power, is one watt. The watt-hour is equal to 3,600 joules. The **kilowatt-hour** is the energy expended in one hour when the activity is one kilowatt. The kilowatt-hour equals 3,600,000 joules.

Power. — The **watt** $= 10^{7}$ absolute units of power (or 10,000,000 ergs per second), and is the power of a current of one ampere flowing under a pressure of one volt. This unit of power is equal to one *joule per second*, and is approximately $\frac{1}{746}$ of one horse-power, or one horse-power is equal to 746 watts. The kilowatt is equal to one thousand watts.

Inductance. — The **henry** $= 10^{9}$ or (1,000,000,000) absolute units of inductance, and is the inductance in a circuit when the E. M. F. induced is one volt, while the inducing current varies at the rate of one ampere per second.

Values of the Ohm. — The difficulty in determining experimentally the correct value of the ohm and volt has lead to the adoption and use of several different values. Three of these are the British Association (B. A.) ohm and volt, the Legal ohm and volt, and the *International* ohm and volt. The value of the ampere has not changed materially because its absolute value may be easily and accurately determined by means of the tangent galvanometer.

The International Electrical Congress held at Chicago in 1893 recommended the adoption of the *International* ohm and volt. United States, England, Germany, and other countries have now adopted and legalized the International units, and the ohm and other electrical units have probably now received their definite and final values.

As the B. A. and Legal ohm are still in use to some extent, it is well to know their values in terms of each other.

1 International ohm = 1.0137 B. A. ohms = 1.0028 Legal ohms.

1 B. A. ohm = .9865 International ohm = .9893 Legal ohm.

1 Legal ohm = .9972 International ohm = 1.0108 B. A. ohms.

The **International ohm** represents the true ohm as nearly as the latter is known (see p. 7).

The **B. A. ohm** is the mean resistance of six of the British Association Committee's original ohm coils, now preserved in the Cavendish Laboratory at Cambridge, England, and representing the results of the Committee's experiments of 1865.

The **Legal ohm** is the resistance recommended to be legalized as the standard unit of resistance by the Congress of Electricians held at Paris in 1884. This unit was defined as the resistance of 106 centimetres of mercury, of one millimetre cross section, at 0° C. It has never been legalized in this country but is still employed in technical work to some extent.

ELECTRICAL MEASURING INSTRUMENTS.

Important Principles. When an electric current passes in a conductor, the current causes the same to be surrounded by a magnetic field or by magnetic lines of force. These magnetic lines encircle the conductor and their direction depends upon the direction of the current.

Owing to the presence of these magnetic lines a pivoted magnetic needle will be deflected when placed near the conductor and will tend to set itself at right angles to the same. This phenomenon is illustrated in Fig. 1, the arrows indicating the direction in which the needle will turn. This direction depends not only upon

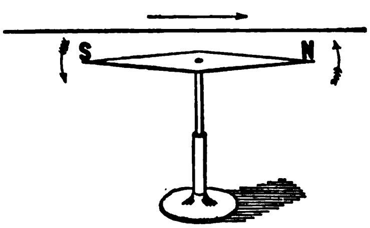


Fig. 1.

the direction of current, but also whether the needle is above or below the wire. If the direction of the current was from right to left in Fig. 1, then the needle would be deflected in an opposite direction to that indicated. If the needle was above the wire and the direction of the current remained as shown, then the needle would be deflected again in an opposite direction.

A convenient rule for remembering the direction of these movements is that suggested by Ampere, which is as follows: Suppose a man swimming in the wire with the current, then if he faces the needle, the north-seeking pole will be deflected towards his left hand.

If the wire passes over the needle and then back under it, as shown in Fig. 2, the effect of the current in both parts of the wire will be to deflect the needle in the same direction. This will be clear by applying Ampere's rule to the upper and lower parts of the wire, the north-seeking pole in each case being deflected as shown. By passing the wire around the needle several times, or in other words by suspending the needle at the center of a coil of wire which carries a current, the deflection of the needle will be much increased, as the effect of each turn is added to that of the others.

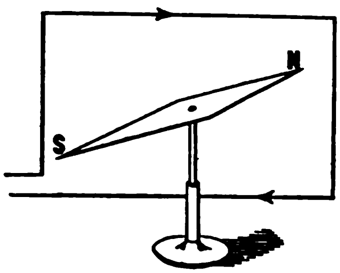


Fig. 2.

This may be more fully understood by considering Fig. 3. When no current is passed through the coil, the needle will come to rest and place itself parallel to the lines of force of the earth's magnetism. The direction of these lines is nearly north and south. Suppose the coil to be placed parallel to the needle and the current then passed through the coil. The needle will come to rest in an oblique direction which will be the direction of the resultant field due to the current in the coil and to the earth's magnetism. The less the strength of the earth's magnetism and the greater the strength of the field due to the current in the coil, the greater will be the deflection of the needle towards a position at right angles to the coil. Hence the deflection may be increased by increasing the number of turns or length of wire in the coil, and by increasing the current.

Another phenomenon upon which many electrical instruments depend is the deflection of a coil carrying a current. Such a coil, as we have learned, is surrounded by a field similar to that of a magnet, and therefore if it is free to turn, it will take up a position such that the magnetic lines passing through it due to the current, and the magnetic lines of the earth's magnetism will coincide in direction; that is, the coil will move so as to include a maximum number of lines of force. The ends of the coil will then point in a direction which is nearly north and south as is the case with a compass needle. If the coil is in the neighborhood of a powerful magnet the earth's magnetism will then have practically no effect and the position of the coil will be almost entirely influenced by the magnet. The movement of the coil may be caused by a field produced by another fixed coil as well as by a permanent magnet.

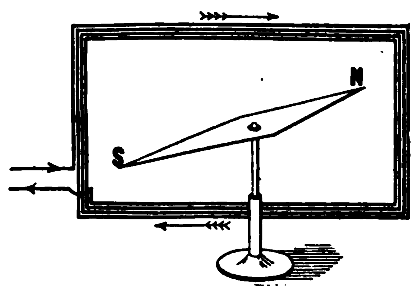


Fig. 3.

Galvanometers. Galvanometers are instruments used for determining the strength or presence of an electric current. These instruments were formerly the only ones used to measure current strengths, and are still largely used in the electrical laboratory for accurately determining the strength of very small currents.

There are two general forms of these instruments; in one the strength of current is determined by the deflection of a magnetic needle suspended at the center of a coil of wire through which the current is passed; in the other the current strength is determined by the deflection of a movable coil carrying the current and which is suspended between the poles of a fixed permanent magnet.

Tangent Galvanometer. This form of galvanometer consists of a coil of wire of many turns and of large radius having a magnetic needle supported or suspended at its center, as indicated in Fig. 4. For accurate results the diameter of the coil must be at least ten times the length of the needle. The needle is usually about one-half an inch in length and in order that its deflections may be easily determined, it carries a long light pointer which swings over a graduated circle. In using the instrument care must be taken to have the plane of the coil in a vertical position and parallel to the lines of force of the earth's magnetism.

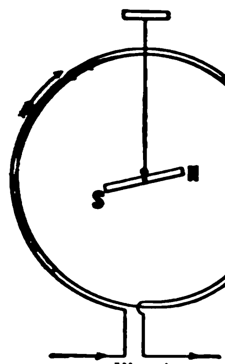


Fig. 4.

Sine Galvanometer. The sine galvanometer is similar in construction to the tangent except that the coil is movable about a vertical axis. Also the length of the needle may be considerably greater thus making the instrument more sensitive. In measuring current strength by the sine galvanometer the coil is first placed parallel to the needle as in the case of the tangent galvanometer, and the needle is then deflected by the passage of the current. The coil itself is next turned about its vertical axis until it is parallel with the deflected needle. Knowing the amount of deflection from the original position the value of the current may be determined.

Astatic Galvanometer. This is a very sensitive form of galvanometer owing to the use of what is known as an astatic pair of needles. If two magnetic needles of equal strength and length are held together with their opposite poles next to each other, as indicated in Fig. 5, they will be independent of the earth's magnetism. One needle will be acted upon to the same degree as the other, and as they are opposite there will be no resultant effect. Hence, if the pair is suspended by a fine silk fibre the needles may come to rest in any position. Owing to the difficulty of magnetizing two needles to exactly the same strength, and of joining them together so that they are parallel, such a pair of needles will have a *slight* tendency to point north and south. If a coil of wire is wound about one of the needles, as shown in Fig. 5, the pair may be deflected by the passage of a very feeble current in the coil. The current passing below one of the needles and above the other,

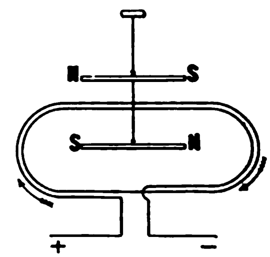


Fig. 5.

tends to deflect both in the same direction; and as the action of the earth upon them is very slight the deflection may be very great. When the deflection is small the current is proportional to the amount of deflection, hence if it is known that a certain current deflects the pair 4°, then a current deflecting the needle 8° will have twice the strength.

Thomson or Mirror Galvanometer. This is the most sensitive form of galvanometer, and is illustrated in Fig. 6. The galvanometer is supported on three screw feet by which the instrument may be leveled. The needles which are usually pieces of steel watch-spring, form an astatic system and may consist of two or more combinations. A small concave mirror is attached to the upper combination and the whole is suspended by a very fine silk or quartz fibre. A permanent magnet called the *control* or *field*

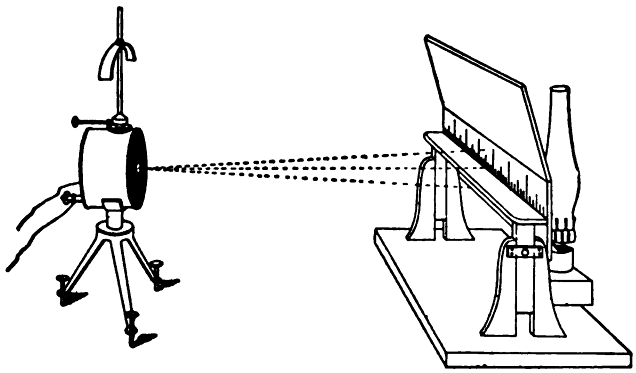


Fig. 6.

magnet is supported above the galvanometer as shown. This may be placed so as to counteract the earth's magnetism, and as it is nearer the upper needle it also serves as a directing or controlling magnet. If the field magnet is removed the magnetic system of needles will come to rest as directed by the earth's magnetism since the system cannot be perfectly astatic. The field magnet may then be lowered in position until the earth's magnetism is counteracted. It is then slightly raised, permitting a feeble directive force to act on the system. Deflection will then take place with an exceedingly small current passing through the coil.

In using this instrument a line of light from a lamp is thrown on the concave mirror of the galvanometer which reflects it to a graduated scale, as shown in the figure. The scale may be about 3 feet in length and situated about the same distance from the galvanometer. The current is approximately proportional to the deflection of the light on the scale when this deflection is small.

Usually one coil is used, one of the needles being suspended at its center. The coil is divided vertically into two separate parts to give access to the needle and mirror. For greater sensitiveness two coils may be used one above the other, each of which has one needle of the astatic pair suspended at its center. As each coil is divided into two parts, such an instrument is usually called a four-coil galvanometer.

Differential Galvanometer. This galvanometer is used for the purpose of comparing two currents. One coil may be used having two similar independent windings or there may be two separate coils. If equal currents are passed through the windings in opposite directions the resultant effect on the needle at the center will be zero, and there will be no deflection. If the currents are unequal the deflection will be proportional to the difference between them. A Thomson galvanometer may be made differential by connecting the coils so that the current passing through one set will be opposite to that passing through the other.

Ballistic Galvanometer. The needle of this galvanometer is so constructed as to have a slow period of oscillation, and therefore may be used to measure the strength of currents which are of short duration. The charge of a condenser may be measured by discharging it through this form of galvanometer. As the needle is slow to turn the varying impulses of the current of discharge are allowed to produce their full effect. The quantity of electricity flowing through the coil is determined from the maximum deflection of the first swing.

D'Arsonval Galvanometer. The D'Arsonval galvanometer is quite different from preceding forms in that the *coil* is suspended and deflected by the passage of a current. The arrangement is as shown in Fig. 7. The coil through which the current passes is suspended between the poles of a strong, permanent, horse-shoe magnet. The coil consisting of very fine wire is wound upon a small rectangular frame and is suspended by thin platinum silver strips. The current is passed into and out of the coil through these strips. A small concave mirror is usually carried above the coil as the deflection may then be more accurately determined. Within the coil is fixed a cylindrical soft iron core which serves to concentrate the lines of force passing between the poles, and thereby produces a strong magnetic field in which the coil moves. The tendency of the coil to turn so as to include the greatest number of lines of force when a current is passed through it, is resisted by the torsion of the suspending wires. The deflection produced is directly proportional to the current, the number of turns and the intensity of the magnetic field. The magnet is built up of laminations of hardened steel which is treated so that it will maintain the strength of its magnetism.

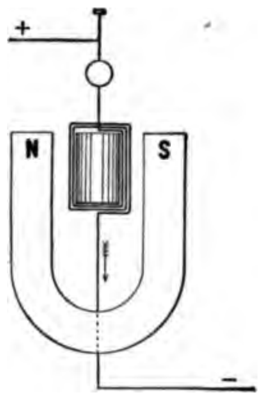


Fig. 7.

The D'Arsonval galvanometer has several important advantages over the Thomson and has largely replaced the latter. Owing to its strong magnetic field this galvanometer is not affected by the magnetism of the earth or other external magnetism. It may therefore be used in close proximity to dynamos or other machines without being affected by them. As the factors upon which the deflection depends may be made invariable for long periods of time, there is no necessity of frequently testing the instrument.

Shunts. If a current is passed through a galvanometer and a very large deflection is produced, there is liable to be a large error in determining the strength of the current, as accurate results are only obtained when the deflection is small. Moreover if a large current is passed through the coil, the instrument will be injured. It is therefore customary to use a shunt about the galvanometer. Part of the current then passes through the galvanometer and part through the shunt, the division of current being inversely as the resistances of the two branches. If the resistances of the shunt and galvanometer are known then the total current may be easily calculated. For example if it was found that .008

ampere flowed through the galvanometer and that the shunt resistance was $\frac{1}{99}$ of that of the instrument, then the total current would be .8 ampere; for the current passing through the shunt was 99 times as great as that through the galvanometer and the total current is the sum of the two, or $100 \times .008 = .8$ ampere. Shunts for galvanometers are adjustable so that the ratio of their resistance to that of the galvanometer is equal to $\frac{1}{999}$, $\frac{1}{99}$, or $\frac{1}{9}$ as desired. With these ratios the total current passing will be respectively equal to 1,000, 100, or 10 times the value of that passing through the galvanometer.

When taking a measurement the shunt should be adjusted so that only a small portion of the current is at first allowed to pass through the galvanometer. If the deflection is too small the resistance of the shunt may be increased until a suitable deflection is obtained. When the shunt circuit is broken the total current passes through the galvanometer obtaining the maximum deflection.

The number by which the current passing in the galvanometer is multiplied to obtain the total current is called the ***multiplying power of the shunt***. This is equal to one plus the ratio of the galvanometer resistance to the shunt resistance.

Voltmeters. Voltmeters are instruments used for measuring the potential difference between two points in a circuit. They are provided with a scale graduated in volts over which a pointer is deflected; the position of the pointer indicating the potential difference. In many cases voltmeters depend upon the same principles as galvanometers. If a high resistance is connected in series with the coil of a galvanometer, only a small current will pass when the leads from the coil and resistance are connected to points differing greatly in potential. The current will vary directly as the potential difference and the deflection of the needle will therefore be proportional to this difference.

Weston Voltmeter. This instrument is very much used and is similar to the D'Arsonval galvanometer. The permanent magnet is horizontal instead of vertical, and is similar in shape to the outline of the brass case which encloses the working parts. The magnet is provided with pole pieces which are carefully shaped, allowing the air gap between them and the coil to be small. Fig. 8 illustrates the arrangement. Between the pole pieces N and S

is fixed a cylindrical piece of soft iron *E* serving to conduct the lines of force. The coil *F*, which is wound upon an aluminum frame, is supported by jewel bearings inserted in fixed brass cups *A* and *B*. A directive force is given to the coil by two delicate springs *C* and *D* which are opposed to each other. The coil carries a light pointer which swings over a scale graduated in volts. A high resistance is enclosed within the case of the instrument and is connected in series with the coils, the current being led to and from the coil through the springs *C* and *D*.

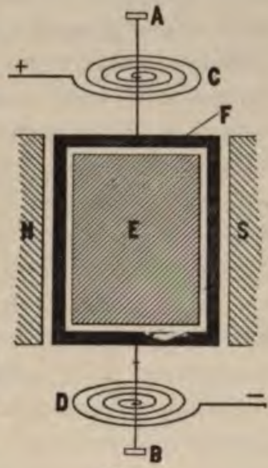


Fig. 8.

A Weston portable voltmeter is illustrated in Fig. 9. The lower right-hand binding post is for the positive terminal. If the negative terminal is connected to the lower left-hand binding post the upper graduation of the scale is used and readings may be

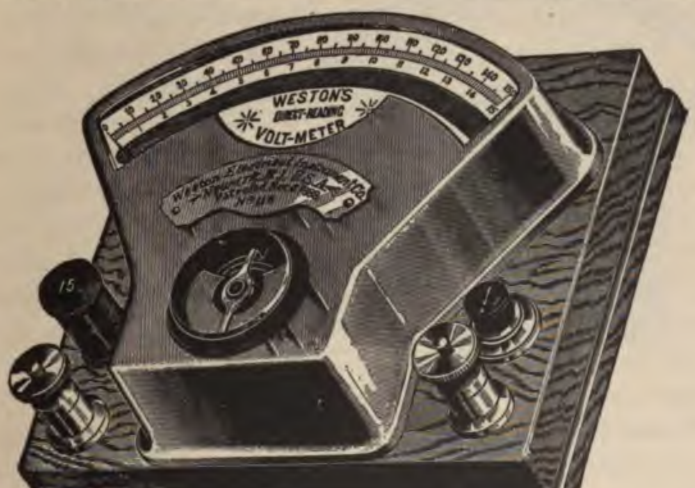


Fig. 9.

taken up to 150 volts. If the negative terminal is connected to the binding post marked 15, then the lower graduation of the scale is used, the maximum deflection indicating 15 volts. When the latter connection is made the resistance of the instrument is only one tenth of what it is in the former case. The current in the coil (for the same voltage) is therefore ten times as great and the deflection ten times as much. The total resistance of the instrument is about 17.000 ohms. This voltmeter can be used for very high voltages by connecting a large resistance in series. If a resistance ten times that of the voltmeter is connected in series with the instrument, the deflection will only be one tenth of what it would be without this resistance, and hence the maximum deflection will indicate 1,500 volts.

Ammeters. The only essential difference between a voltmeter and an ampere-meter or ammeter, is in the resistance of the instrument. In a voltmeter it was desired that it should have a very high resistance so as to take only a very small current and therefore consume only a small amount of energy. In measuring current strength however, the ammeter must be connected in series in the main circuit, and hence it is desirable that its resistance should be as low as possible so that the energy consumed ($I^2 R$) will be slight. The scale of the ammeter is graduated to indicate amperes directly.

Fig. 10.

The Weston ammeter is very similar in form and construction to the voltmeter, except that in the former instrument the moving coil is connected in parallel with a low resistance shunt through which the main current passes. Therefore the greater the main current, the greater will be the current passing through the coil. The Weston instruments are generally recognized as the most accurate on the market. Besides the form of instrument illustrated in Fig. 9, the Weston voltmeters and ammeters are made in a form for station use. A station ammeter is illustrated in Fig. 10. The connections to the instrument are made at the back of the switchboard. The instrument illustrated has a translucent scale which is illuminated by an incandescent lamp supported in the rear.

Electromagnetic Ammeters. Many ammeters have been constructed upon the principle of the electromagnet. The Edison pendulum ammeter is a simple example of this class. The arrangement is illustrated in Fig. 11. When the current to be measured is passed through the coil it draws in the soft iron core *C*, which

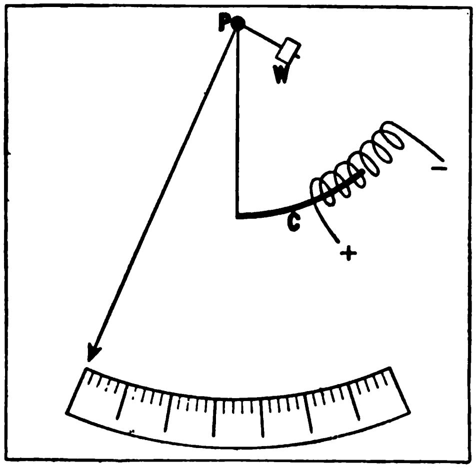


Fig. 11.

is pivoted at *P*. The needle is fixed to the core piece at *P*. The core is drawn into the coil against the force of gravity, the weight *W* serving as an adjustment. The greater the current in the coil, the greater is the deflection of the needle.

Instruments of this type are not very accurate especially at low readings. There is some error due to hysteresis in the iron core, which causes the readings to be too low for an increasing current and too high for a decreasing current. The advantages of this form of ammeter are simplicity and cheapness.

Current Balance. The Kelvin current balance is a very accurate instrument for measuring current strength. It depends for its action upon the force of attraction or repulsion exerted between coils carrying a current. It consists of six coils two of which *A A* in Fig. 12 are movable, and four, *B B B B* are fixed.

The movable coils may be considered as the scale pans of a balance, being supported at the center *C*. The current passes through all of the coils in series, the direction being such that the mutual action causes one of the movable coils to rise and the other to

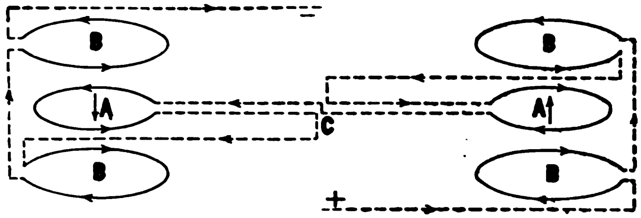


Fig. 12.

descend. This tendency is balanced by a sliding weight on the arm, the position of the slider when the arm is horizontal indicating the strength of current.

Electrodynamometer. This instrument is also used to measure the strength of current by the mutual action of two coils carrying the current. The Siemens dynamometer represented in Fig. 13, is one of the oldest and simplest of these. It consists of two coils *A* and *B* at right angles to each other, through which the current passes in series. One of the coils, *A*, is movable and is supported by a pivot bearing. A spiral spring *C* is attached to this coil and to the torsion head *D*. The current is introduced through mercury cups in which the terminals are immersed. This coil carries a pointer which extends up and over a circular scale. The torsion head also carries another pointer. When a current is passed through the coils, the movable one tends to move so as to include the greatest number of lines of force and to set itself parallel to the fixed coil. The torsion of the spring opposes this movement. The torsion head is then turned until it exactly counterbalances the turning moment of the coil, which is indicated when its pointer is at the zero reading of the scale. The angle

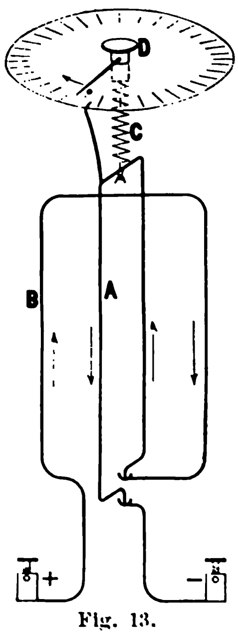
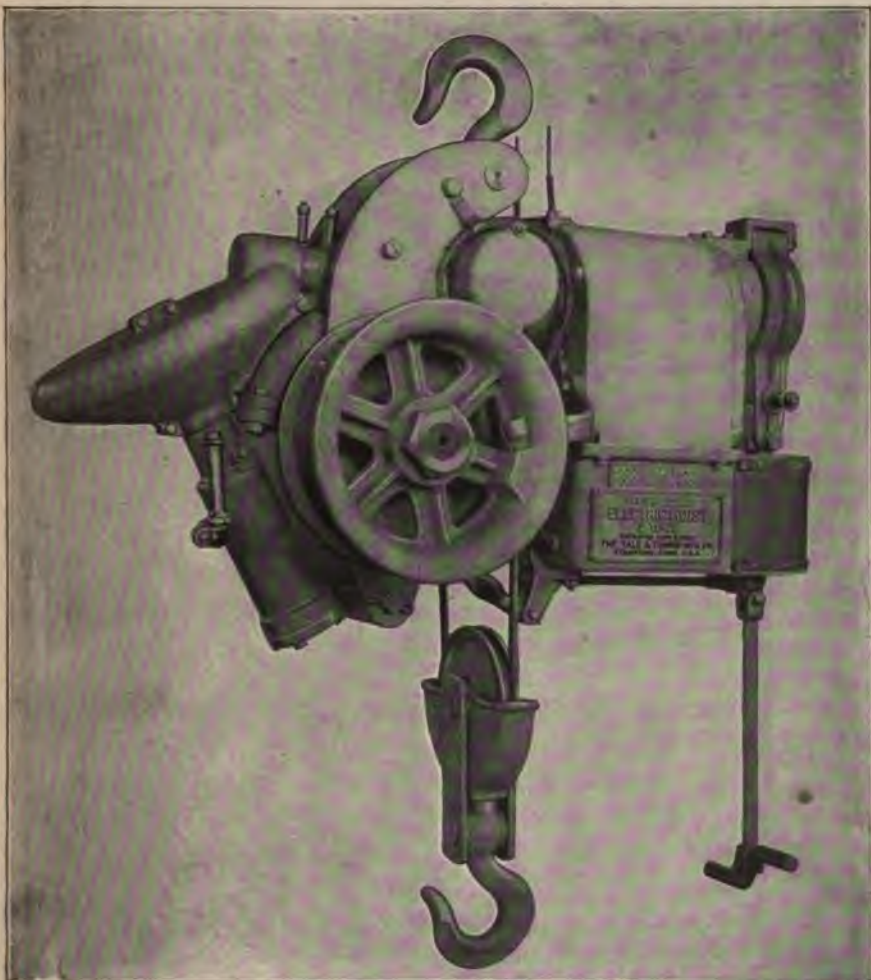


Fig. 13.



ELECTRIC PORTABLE HOISTING MACHINE.

Yale and Towne Mfg. Co.

through which the torsion head is turned, as indicated by the pointer, varies directly as the square of the current strength. The scale may be graduated to read directly in amperes.

This instrument is serviceable for alternating currents as well as direct, and has the further advantages of being very accurate within certain ranges and of being very free from variable errors.

Cardew Voltmeter. The principle of this instrument depends upon the heating effect of a current. A current passing in a wire heats it and causes it to expand. In the Cardew voltmeter the expansion and contraction of a long fine platinum silver wire is made to move a pointer over a scale graduated in volts. The greater the potential difference at the ends of the wire, the greater will be its current and the more it expands. The voltmeter may be used for either the direct or alternating current as the heating effect is the same. The instrument is subject to many errors and requires therefore the greatest care in its manufacture. It is somewhat awkward to use as it is about three feet in length. Another objection is the comparatively large amount of energy it consumes.

Electrostatic Voltmeters. The principle that two oppositely charged bodies attract each other is applied in the electrostatic voltmeter. The Thomson vertical electrostatic voltmeter is shown in Fig. 14. It consists of two fixed parallel metallic plates *A*, between which is the movable plate *B*. The plate *B* is paddle shaped and supported by two knife edges at its center. This plate carries a pointer which swings over the scale, and is weighted at the lower end to give it a directive force. To measure the difference of potential between two points, the fixed plates are electrically connected to one point and the movable plate to the other. The two fixed plates then become charged with say positive electricity, and the movable plate with negative electricity. The plate *B* is then attracted toward the fixed plates, and deflected from the vertical position to an extent depending upon the difference in potential between them. The force of attraction varies as the square of the difference of potential. The scale is graduated to read directly in volts. It is immaterial whether the fixed plates are charged positively and the movable plate negatively or if the reverse is the case. The force of attraction in each case is the same. The instrument may therefore be used equally well for alternating or direct currents.

The electrostatic voltmeter is useful only in measuring potential differences greater than 50 volts. They cannot be made delicate enough to measure below that figure with accuracy. They are however, specially desirable in measuring high potential differ-

Fig. 14.

ences. They are simple in construction and have the great advantage that they consume no energy, since no current passes through the instrument.

Wattmeters. The power consumed in a circuit supplied with a direct current is equal to the product of the amperes and E. M. F. in volts. An instrument which measures electrical energy must, therefore, take these two factors into consideration.

The Siemens electrodynamometer may be adapted to measure the number of watts consumed in a circuit by having one of the coils serve the purpose of a voltmeter, and the other that of an ammeter. If one of the coils is made of high resistance, having a large number of turns of fine wire and shunted across the circuit terminals, and the other coil made of low resistance, having a few turns of coarse wire and connected in series with the circuit, then the mutual action between them will be proportional to the product of the volts and amperes. The angle through which the torsion head must be turned to bring the movable coil back at right angles to the fixed coil will be proportional to the energy supplied to the circuit. The scale may be graduated to read directly in watts.

This instrument is more useful in alternating current work than for direct currents. Multiplying the voltmeter and ammeter readings together will give the correct number of watts only in the case of the direct current. With the alternating current this product must be further multiplied by what is known as the *power factor*. The determination of the value of this power factor is somewhat difficult. The wattmeter, on the other hand, gives the true watts directly, and, therefore, is very convenient for alternating currents

Recording Meters. Electrical instruments are sometimes made to give a continuous record of the volts, amperes, or watts of a circuit. This may be accomplished by attaching a pen to the indicating part of the instrument; then if a strip or circular piece of paper is moved by clockwork beneath the pen, a line will be traced showing the volts, amperes, or watts at any time. These instruments cannot be made as sensitive as those which are not recording and are therefore less accurate. They also consume more energy.

The Thomson is one of the best recording wattmeters, and is a motor of simple construction. It consists of two coarse wire coils placed in series with, and a fine wire coil connected in shunt around, the circuit whose power is to be measured. The coarse wire coils form the field which causes the fine wire coil to revolve. The shunt coil is supported in bearings and its rotation is proportional to the energy of the circuit. A copper disk is mounted on the same shaft as the shunt coil and rotates between the poles of a permanent magnet. The currents induced in this disk serve as a drag, the drag being adjusted to give a speed proportional to the watts supplied. The number of revolutions is recorded by clockwork and the instrument is graduated to indicate watt-hours.

Water Rheostats are very convenient for absorbing power during electrical tests and are easily made adjustable. A very serviceable form is illustrated in Fig. 15. It consists of a stout barrel containing water through which the current is passed. The current is introduced through the insulated wire *A*, which is attached to a terminal plate *D*. From this plate the current passes to plate *C* and through the main *B*. The plates may be of perforated iron; a stove grate serves very well as it gives a large surface contact. To the wire *B* is attached a cord passing over pulleys and having a counter-weight at its other end. The plate *C* may then be raised or lowered and will remain in any desired position. The resistance of the rheostat depends, of course, upon the distance between the plates. Small pieces of wood should be attached to one of the plates to prevent them from accidentally coming into contact, and so producing a short circuit. The conductivity of the water may be greatly increased by the addition of sodium carbonate or sulphuric acid. A rheostat constructed as above is capable of absorbing about 10 H. P.

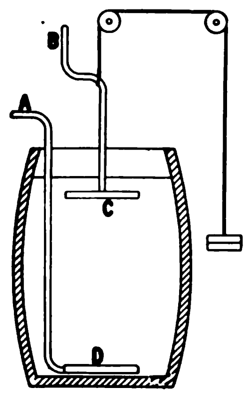


Fig. 15.

Carbon Rheostats. These rheostats consist of a series of carbon blocks or plates in contact with each other through which the current is passed. They are supported by some insulating material such as slate, and arranged so that by turning a hand-wheel the blocks may be pressed closely together or allowed merely to touch. Their resistance is varied in this manner as the closer the plates the less is the resistance. A very exact adjustment may be obtained by the use of these rheostats. Heating caused by the continued passage of a current decreases their resistance.

Wire Rheostats usually consist of German silver wire supported on a frame and arranged so that the whole or parts may be included in a circuit. This is accomplished by making contact at different points along the wire, either by a switch or by sliding clips.

The wires are sometimes strung or wound on wooden frames, and their carrying capacity is then limited by the charring of the wood. A current of two amperes passing through No. 28 German silver wire and a current of eleven amperes through No. 19 wire will cause charring of pine wood.

Wire rheostats which are to carry large currents should not be boxed in, as the free access of air greatly increases the carrying capacity. By immersing wires in an oil bath, their carrying capacity may be increased about four times. Overheating can be prevented by running cold water through pipes immersed in the oil.

Lamp Rheostats. Incandescent lamps are often used as a means of absorbing power or of obtaining a certain E. M. F., or current strength. Such a rheostat may consist of any number of lamps arranged so that they may be connected in series or in parallel between mains. The greater the number connected in parallel the greater is the current taken from constant potential mains.

RESISTANCE MEASUREMENT.

Measurement of resistance is made by comparison with certain standards of known resistance, the different methods of measurement varying to a great degree. The standard resistance coils are made of such alloys as German silver, platinum silver, or platinoid. These alloys have a high specific resistance and change their resistance with rise in temperature to a much less extent than other metals. It is of course desirable that this change should be as small as possible. The size and length of the coils are such that they have resistances of a definite number of ohms at a certain temperature. The coils are insulated with silk or paraffined cotton and are very carefully wound. Each wire is doubled on itself before being coiled up, and then wound as shown at *A* and *B* in Fig. 16. Self-induction and consequent sparking on opening and closing their circuit is thus avoided. The ends of the coils are soldered to brass pieces as *C*, *D*, *E*. Removable conical plugs *F*

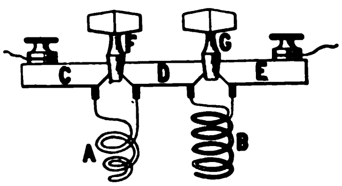


Fig. 16.

and *G* of brass are made to fit accurately between the brass pieces. When these are inserted as shown, the coils will be short circuited and a current will pass directly through *C*, *F*, *D*, *G* and *E* without going through the coils. If *F* is withdrawn the coil *A* will then be inserted in the circuit; if *G* is also withdrawn then coils *A* and *B* will both be inserted, as the current cannot pass from *C* to *E* without going through the coils.

Resistance boxes are constructed consisting of a large number of resistance coils, and of such resistances that by withdrawing plugs varying resistances may be built up. A common form of resistance box has coils of the following ohms resistance: 1, 2, 2, 5, 10, 20, 20, 50, 100, 200, 200, 500, 1,000, 2,000. A resistance of 497 ohms could be made up by withdrawing plugs corresponding to the coils $200 + 200 + 50 + 20 + 20 + 5 + 2 = 497$, or 768 by coils $500 + 200 + 50 + 10 + 5 + 2 + 1 = 768$.

Resistance by Substitution. By Ohm's law the greater the resistance inserted in a circuit the less becomes the current, provided the E. M. F. remains constant. This gives us a simple although not very accurate method of measuring electrical resistance. If a battery of constant E. M. F., the unknown resistance, and a simple galvanometer are connected in series, the strength of the current passing will be indicated by the latter. Suppose the unknown resistance to be replaced by known resistances, enough resistance coils being inserted so that the deflection of the galvanometer needle is the same as when the unknown resistance was in circuit. The current will then be the same, and as the E. M. F. remains unchanged, the resistances must be equal in each case. The sum of the known resistance coils inserted will then be equal to the unknown resistance.

The advantages of this method are that it is rapid, and that only crude apparatus is required, as the galvanometer and resistance box can be very simple in form. The resistance of the battery and galvanometer should be but a few ohms, otherwise small resistances cannot be measured closely. Only small currents should be used so that the error from heating may be negligible.

Wheatstone Bridge. All ordinary measurements of resistance are usually made by use of the Wheatstone bridge.

The principles of this instrument will be understood from Fig. 17. There are four arms to the bridge with the resistances *M*, *N*, *X*, and *P*. From the points of junction *A* and *C*, wires connect with a battery *E*. A galvanometer *G* is connected between the junction points *B* and *D*. The current from the battery divides at *A* and passes through the resistances *M* and *X*, and *N* and *P*, uniting again at *C*. The fall of potential between *A* and *C* must of course be the same in amount through the resistances *M* and *X*

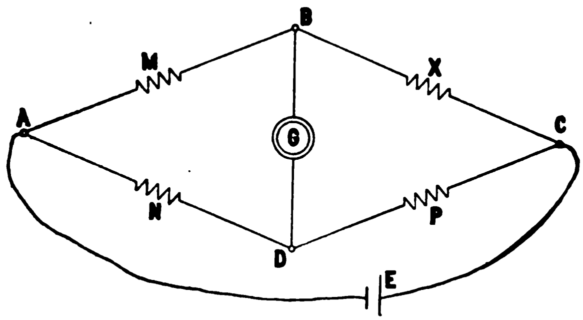


Fig. 17.

as through *N* and *P*. If no current passes through the galvanometer then the points *B* and *D* will be at the same potential, and there will be the same fall of potential in the resistances *M* and *N*, and in the resistances *X* and *P*. Under these circumstances the ratio of the resistances of *M* to *N* will be the same as *X* to *P*, or

$$\frac{M}{N} = \frac{X}{P}.$$

If *M*, *N*, and *P* are known resistances, the resistance of *X* is readily found by the formula,

$$X = \frac{M}{N} \times P.$$

The method of using the bridge will be better understood from Fig. 18. The bridge arm *M* has coils of 1, 10, 100 ohms resistance, and arm *N* coils 10, 100, 1000. The series of coils *P* for obtaining a balance usually has resistances of 1, 2, 2, 5, 10, 20, 20, 50, 100, 200, 200, 500, 1,000, 2,000 ohms, but coils up to 100 only are shown. There is a key *K* in the galvanometer circuit and a key *H* in the battery circuit. The battery key *H* should always be closed *before* the galvanometer key *K*, and should be kept closed until after K is opened. This not only insures steadiness in all currents when the galvanometer circuit is closed, but also protects the galvanometer from self-induction currents which would occur if the battery circuit were closed after that of the galvanometer. A reflecting galvanometer is used in making accurate measurements.

In making a measurement of an unknown resistance it is first necessary to gain a knowledge of its approximate resistance. For this purpose the 100-ohm plug is withdrawn from both arms M

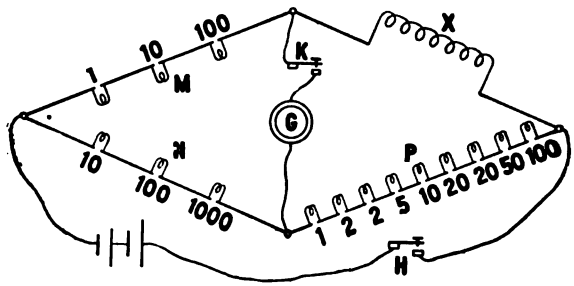


Fig. 18.

and N, the unknown resistance being connected at X. The ratios of M to N will then be unity, and hence for a balance the number of ohms required in the resistance coils P will be the same as the resistance X. The 1,000-ohm plug in P should first be drawn and the keys depressed in their proper order for an instant only. The galvanometer needle or mirror, as seen by the light reflected on the scale, is deflected — say to the right, and the resistance is probably too large. The plug is replaced and the 1-ohm coil withdrawn. On depressing the keys suppose the spot of light is deflected to the left. Then the 1-ohm is too small and the 1,000 ohms too large; also in this case deflections to the right mean that the resistance inserted is too large, and deflections to the left mean that the resistance inserted is too small. The 1-ohm plug is now replaced, and 500, 200, etc., are successively tried until it is found that 12 ohms is too large and 11 ohms too small, that is, the unknown resistance is between 11 and 12 ohms.

Suppose that it is desired to find the correct value of the unknown resistance to the second place of decimals. The ratio of the arms M to N must then be changed so that the resistance coils

P will have a value of between 1,100 and 1,200 ohms when a balance is obtained. The ratio of *X* to *P* will then be 11 to 1,100 approximately, or about 1 to 100. To obtain a balance the ratio of the arms *M* to *N* must also be 1 to 100. Hence the 100-ohm plugs withdrawn in the first determination are replaced and the 10-ohm plug withdrawn from *M* and the 1,000-ohm plug from *N* giving the required ratio. The same ratio could be obtained by withdrawing the 1-ohm plug in *M* and the 100-ohm plug in *N*.

The bridge is now arranged for the final measurement. As the resistance in *P* will now be over 1,100 ohms, the 1,000 and 100-ohm plugs are first removed. Suppose the 50-ohm plug to be also removed, and a deflection to the right shows that this is too great. The plug is replaced and 20 withdrawn, which proves to be too small. The next twenty plug is also withdrawn and a deflection to the left shows the resistance to be still too small. The 5, 2 and 2-ohm plugs are successively withdrawn, the last two ohms proving to be too great. This is replaced and the 1-ohm plug withdrawn, and suppose no deflection is then obtained. The total number of ohms in *P* is now $1,000 + 100 + 20 + 20 + 5 + 2 + 1 = 1,148$. The value of *X* is therefore $\frac{10}{1000} \times 1,148 = 11.48$ ohms.

The above example illustrates the general method of using the bridge. Usually the resistance to be measured is known approximately and the required ratio between *M* and *N* can be determined without making a preliminary measurement. The possible changes in the ratio between *M* and *N* gives the bridge a great range of measurement. When *M* is 1 and *N* is 1,000 ohms, measurements of resistance as small as .001 ohm may be made. Bridges are usually arranged with a reversing key so that *M* and *N* may be interchanged, hence *M* could be 1,000 and *N* 1, and measurements of resistance as high as 4,110,000 ohms could be made with the bridge we have considered.

Portable Testing Set. There are many different varieties of bridges and their form always differs from that of the diagrams in Figs. 17 and 18. A portable testing set including Wheatstone bridge, galvanometer, battery, and keys, is illustrated in Fig. 19. The rheostat of the bridge is made up of coils, 16 in number, of denominations 1, 2, 3, 4, 10, 20, 30, 40, 100, 200, 300, 400, 1,000.

2,000, 3,000, 4,000 ohms — 11,110 ohms in all. Bridge coils are 1, 10, and 100 on one side and 10, 100, and 1,000 on the other. A reversing key admits of any ratio being obtained in either direction so that the range of the set is from .001 to 11,110,000 ohms.

Fig. 19.

It is, however, impossible to construct a portable galvanometer of sufficient sensitiveness for these measurements, and the actual limits are from .001 ohm to 300,000 or 400,000 ohms.

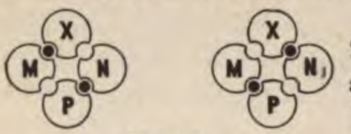


Fig. 20.

The reversing key, shown in Fig. 20 consists of the blocks M, N, P, and X and two plugs which must both lie on one diagonal or the other. The blocks are connected with the resistances indicated by their letters. In the left-hand figure M is connected with X and N with P, and the bridge arms have the relation

$$\frac{M}{N} = \frac{X}{P}, \text{ or } X = \frac{M}{N} \times P.$$

In the right-hand figure M is connected with P and N with X, the bridge arms then having the relation

$$\frac{M}{N} = \frac{P}{X}, \text{ or } X = \frac{N}{M} \times P.$$

The advantages of having a reversing key in the bridge arms are; the increase in range obtained, six coils being made to do the work of eight, and also that any error in the initial adjustment of the bridge arms can be readily detected by having the two arms equal, balancing and reversing. Unless the resistance of the coils inserted in *M* and *N* are exactly equal, the system will be unbalanced after reversing.

The galvanometer, the needle and scale of which are shown at the left in Fig. 19, is of the D'Arsonval type, and the coil is mounted in jewels. As this galvanometer is not affected by external magnetic fields or electric currents, it is suitable for dynamo or shop testing. The key for closing the galvanometer circuit is shown in front at the right.

The battery is made up of six chloride of silver cells contained in the cell box at the right; flexible leads allow the total number in use to be varied at will. The cells will last a number of months even with daily use. The flexible connecting cords have their terminal sockets combined with small binding posts so that connection may be made to an extra battery or other source of E. M. F. if desired. The left-hand key controls the battery circuit.

A plan of the connections of this testing set is shown in Fig. 21. The two lower rows of coils (marked 1 to 4,000) are connected beneath the top at the right by a heavy copper rod and constitute the rheostat arm, or what corresponds to *P*. By withdrawing the proper plugs in these rows any number of ohms from 1 to 11,110 may be obtained.

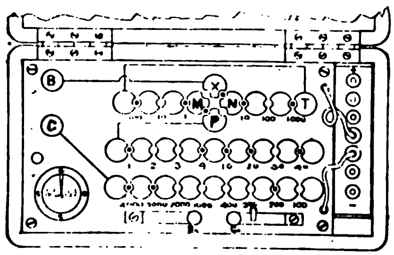


Fig. 21.

The upper row of coils consists of the two bridge arms, *M* at the left and *N* at the right, with the reversing key between them. The two extremes of the upper row are joined by a heavy copper connection and correspond to the point *A* in Fig. 17. The upper block *X* of the reversing key is connected with the binding post *B*, the block *P* is joined to the left of the middle row of coils while the other end of the rheostat combination is connected with the binding post *C*. The resistance to be measured is connected between the terminals *B* and *C*.

Example. — Suppose a balance is obtained —ⁱᵗʰ unknown resistance connected between *B* and *C*, when with drawn as shown in Fig. 21. What is the value of the unknown resistance?

Solution. — The reversing key is arranged so that M is connected with P and N with X, hence

$$\frac{M}{N} = \frac{P}{X}, \text{ or } X = \frac{N}{M} \times P.$$

In the figure $N = 100$, $M = 10$, and $P = 2{,}000 + 1{,}000 + 400 + 300 + 100 + 30 + 3 + 2 = 3{,}835$. Therefore

$$X = \frac{100}{10} \times 3{,}835 = 38{,}350 \text{ ohms.}$$

Ans. 38,350 ohms.

Use and Care of Bridge. Before beginning a measurement it is essential that each plug be examined to see that it is firmly twisted into place, also in replacing a plug the same care should be used. A slight looseness will considerably increase the contact resistance and so introduce errors in the result. For the same reason the plug tapers should be kept clean and the top of the bridge free from dust and moisture. Special care should be taken with the surfaces between adjacent blocks. The plugs should be handled only by their vulcanite tops, and care should be taken not to touch the blocks.

The plug tapers may be cleaned with a cloth moistened with alcohol and then rubbed with powdered chalk or whiting. The powder should be entirely removed with a clean cloth before the plugs are replaced. Sand paper or emery cloth should never be used to clean the plugs or bridge blocks. If there are no idle sockets for the reception of the plugs when they are withdrawn, they should be stood on end or placed on a *clean* surface.

Slide Wire Bridge. The principle of this bridge is illustrated in Fig. 22. The heavy lines represent heavy conducting straps of low resistance. There are binding posts at the ends of each section permitting resistances A, B, R and X to be inserted as shown. Between the ends $C\,D$ is stretched a German silver wire of uniform cross section. A battery and galvanometer are connected as shown. A balance is obtained by sliding the contact point E along the wire until a point is found when no current flows through the galvanometer. Under these conditions the potential at E must be the same as that at F and as in the Wheatstone bridge the ratio of the arms between the battery and galvanometer connections must be equal, hence

$$\frac{R}{X} = \frac{A + a}{B + b}.$$

The resistances a and b are easily obtained from the lengths of the sections of the wire given by a scale fixed near the wire;

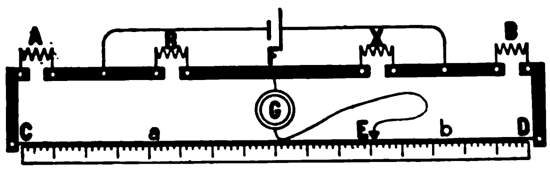


Fig. 22.

then if the resistances of A, B, and R are known that of X may be calculated from the formula

$$X = \frac{B + b}{A + a} \times R.$$

If A and B are replaced by straps of negligible resistance then the value of the unknown resistance may be found from the simple ratio,

$$R : X :: a : b, \text{ giving } X = \frac{b}{a} \times R.$$

Since the resistance of the wire is proportional to its length, the lengths of the sections a and b may be read from the scale and substituted in the latter formula.

This instrument is not well adapted for measuring resistances greater than a few hundred ohms. For very accurate measurements it is necessary to determine and allow for the resistances of the leads from A to C and from B to D.

Example.—If a balance is obtained with the bridge illustrated in Fig. 22, when a is 68.4 centimetres, b 31.6 centimetres, and R 150 ohms, what is the value of X, supposing A and B to be of negligible resistance? Ans. 69.3 ohms approx.

High Resistance Measurement. The standard and most approved method of measuring resistances greater than five or ten megohms is the **direct deflection method.** The main instruments required are a sensitive Thomson galvanometer of high resistance, a variable shunt resistance for the galvanometer, a known resistance of at least .1 megohm, and a source of constant E. M. F. of 100 volts or more. The connections are shown in Fig. 23. The known resistance R is first connected in series with the galvanometer G and testing battery B, through a key K. Care should be taken that the insulation of the apparatus be very high. The

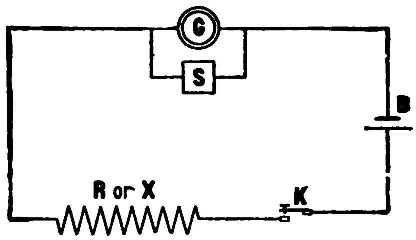


Fig. 23.

shunt S is adjusted to give a suitable deflection of the galvanometer and from this deflection what is known as the *constant* is calculated. The value of this constant is the resistance that must be inserted in the circuit to reduce the deflection to one scale division. The value of the constant is therefore equal to the product of the known resistance R, the scale deflection d, and the multiplying power of the shunt m, or, *constant* $= R\ d\ m$.

As an illustration suppose $R = .1$ megohm, $d = 200$ divisions and $m = 1{,}000$; then *constant* $= .1 \times 200 \times 1{,}000 = 20{,}000$ megohms. This resistance would cause a deflection of only one division, for if $m = 1{,}000$, then if the full current should be passed through the galvanometer, the corresponding deflection would be $1{,}000 \times 200 = 200{,}000$ divisions, as the deflection may be considered proportional to the current. The resistance producing this supposed deflection is .1 megohm, therefore the resistance which would produce a deflection of only 1 division would be $200{,}000 \times .1$, or as found above 20,000 megohms. This follows from Ohm's law, for in order to reduce a deflection by $\frac{1}{200{,}000}$ the current must be reduced by $\frac{1}{200{,}000}$ and consequently the resistance inserted must be 200,000 times as great. This is true, however, only in case the E. M. F. applied remains constant.

After the *constant* has been determined the known resistance R is replaced by the unknown resistance X. The galvanometer shunt is readjusted if necessary and the deflection obtained is again noted. The value of the unknown resistance is then found by dividing the value of the *constant* by the product of the deflection d_1 and the multiplying power m_1 of the shunt used. To continue our illustration suppose $d_1 = 50$ divisions, and $m_1 = 10$. The deflection, if the full current went through the galvanometer, would be $50 \times 10 = 500$ divisions. A deflection of one division is produced with a resistance of 20,000 megohms, hence a resistance producing a deflection of 500 divisions must be $\frac{1}{500}$ of that; then $X = \frac{20000}{500} = 40$ megohms. These steps may be combined and the resistance given at once by the expression

$$X = \frac{R\, m\, d}{m_1\, d_1}.$$

Example.—In a high resistance measurement by the above method the known resistance was .2 megohms, and gave a deflection of 237 divisions, the multiplying power of the shunt being 100. With the unknown resistance inserted, the deflection was 178 divisions with the full current passing through the galvanometer. What was the value of this resistance?

Solution.—In the preceding formula $R = .2$, $m = 100$, $d = 237$, and $d_1 = 178$; also $m_1 = 1$ as the shunt circuit was open. Therefore,

$$X = \frac{.2 \times 100 \times 237}{1 \times 178} = 26.6 \text{ megohms.}$$

Ans. 26.6 megohms.

Voltmeter Method. Another method of measuring high resistance is that in which a sensitive high resistance voltmeter

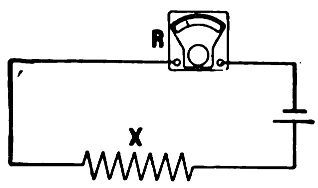


Fig 24.

such as the Weston is used. This method, however, is not so accurate as the preceding and is not adapted to measurements of resistance greater than a few megohms. The voltmeter is con nected in series with the unknown resistance and a source of constant E. M. F. as shown in Fig. 24. With such an arrangement the resistance X will be to the resistance of the voltmeter R, as the volts drop in X is to that in the voltmeter. The drop v in the voltmeter is given by its reading and if the applied electromotive force V is known, the drop in X will be $V - v$. We therefore have the proportion,

$$X : R :: V - v : v,$$

and
$$X = \frac{V - v}{v} \times R.$$

The voltage V, which should be at least 100, may be first determined by measurement with the voltmeter.

Example. — A voltmeter having a resistance of 15,000 ohms, was connected in series with an unknown resistance. The E. M. F. applied to the circuit was 110 volts and the voltmeter indicated 6 volts. What was the value of the unknown resistance?

Solution. — Applying the preceding formula

$$V = 110,\ v = 6, \text{ and } R = 15{,}000,$$

therefore

$$X = \frac{110 - 6}{6} \times 15{,}000 = 260{,}000 \text{ ohms, or } .26 \text{ megohms.}$$

Ans. .26 megohms.

Insulation Resistance. The measurement of insulation resistance is performed by either of the two preceding methods of measuring high resistance. The voltmeter method is the simpler, but since it cannot be used to measure resistances greater than a few megohms, the direct deflection method proves to be the more valuable. The insulation of low potential circuits however, need not exceed five megohms, and in testing such circuits the voltmeter method may be used. If little or no deflection is obtained it is then evident that the insulation is at least several megohms, which is all that is desired. As the insulation of high potential circuits must be greater than five or ten megohms the direct deflection method should then be used.

The connections in testing the insulation of a circuit by these two methods are similar to those shown in Figs. 23 and 24, the resistance X being replaced by the insulation of the circuit. This is accomplished by connecting one wire to the line and the other to

300 K.W. THREE-BEARING GENERATOR.

The C and C Electric Company.

ground such as to a gas or water pipe. The insulation of the line from the earth is then included in the testing circuit; the current passing from the battery, or other source, through the voltmeter or galvanometer to line, from line through the insulation to ground, and then to the battery.

The insulation of a dynamo, that is, the resistance between its conductors and its frame, is tested in a similar manner. This resistance should be at least one megohm for a 110 volt machine but two megohms is to be preferred and is customary. This insulation is measured by connecting one wire to the frame and the other to the binding post, brushes or commutator. The insulation is then included in the circuit. Insulation resistance decreases with increase of temperature so that this test of a machine should be made after a full load run of several hours.

The E. M. F. used should be constant and of one to two hundred volts value. Secondary batteries are the best for this purpose, but silver chloride testing cells are much used. The current decreases from its value, at beginning the test, because of the *electrification* or electrostatic charge of the insulation. For this reason the deflection should not be read until after a certain period of *electrification* — usually one minute. This action is quicker in some materials than in others, and is also greater at low than at high temperatures.

Insulation Resistance of Wire. The direct deflection method is used to test the insulation of short lengths of wire. This is sometimes necessary during manufacture or to test the value of different samples.

At least 200 feet of wire is used. This is made into a coil and immersed in a tank of water. A few inches of the ends of the wire are bared and twisted together; a few feet extending outside the tank. One wire of the testing circuit is connected to the ends of the coil and the other to a metal plate also immersed in the water. The plate should be positive, and the current then passes from this through the water and insulation to the core of the wire. The galvanometer must be provided with a short circuiting key, which is always closed when the battery key is operated, allowing no current then to pass through the galvanometer. Cables in water act like condensers when charged or discharged, and the large current would injure the galvanometer were it not short circuited.

The water should be at a temperature of 75° F., which is generally accepted as the standard. A difference of one degree in the temperature will sometimes cause a difference of several per cent in the insulation resistance. The cable should remain in the water at least 24 hours before the test is made, and it is well to take minute readings of the galvanometer during the first five minutes charging. The insulation resistance is usually calculated from the deflection taken at the end of *five* minutes charging The length of time immersed, temperature, E. M. F., and time of charging should always be stated in a report of a test. Knowing the insulation resistance and length of the sample, the insulation resistance per mile is found by multiplying this resistance by the length expressed in miles. For example, if the insulation for a length of .3 mile was found to be 1,800 megohms, then for a mile of the cable the insulation would be only 1,800 × .3 = 540 megohms, for of course the longer the cable, the less will be the insulation resistance. The insulation of a good cable should be from 400 to 1,000 megohms per mile.

Example. — In measuring the insulation resistance of 250 feet of wire by the direct deflection method, the deflection after five minutes charging of the cable was 15 scale divisions, the full current passing through the galvanometer. In determining the constant the known resistance was .1 megohm, and the deflection 204 divisions, the multiplying power of the shunt being 10,000. Compute the value of the constant, the insulation resistance of the sample, and the insulation per mile.

Solution. — As the constant is equal to the product of the known resistance, deflection and multiplying power of the shunt, we have,

$$\textit{constant} = .1 \times 204 \times 10{,}000 = 204{,}000 \text{ megohms.}$$

The insulation of the sample is equal to this resistance divided by the product of the deflection after five minutes charging and the multiplying power of the shunt then used. As the full current passed through the galvanometer this latter quantity is unity.

The insulation is therefore

$$\frac{204,000}{15} = 13,600 \text{ megohms.}$$

The insulation per mile is

$$13,600 \times \frac{250}{5280} = 644 \text{ megohms (nearly).}$$

Resistance of Conductors. The conductivity resistance of telegraph lines, cables, etc., which are already installed, is measured by use of the Wheatstone bridge. One end only of the conductor whose resistance is to be measured is then at hand, and this is joined to one of the terminals of the bridge while the other bridge terminal is connected to earth. The distant end of the wire is also connected to earth and the measurement then made in the usual manner.

The earth resistance between the two ends of the wire is then included with the unknown resistance but the former is considered negligible. There are two factors, however, which may lead to considerable error in the result; first, the presence of earth currents, and second, the connections to earth may be defective.

When it is possible the *loop* test should be used. The distant ends of *two* wires are then connected together while the near ends are connected to the bridge terminals. The total resistance of the two wires is then measured. This method does not, however, give the resistance of a single wire. One of the best methods of obtaining this is the following:

Three wires and three measurements are required. Let the resistances of the three wires *1*, *2* and *3* be respectively r_1, r_2, and r_3. First wires *1* and *2* are looped at their distant ends and suppose their resistance is found to be R_1; next wires *1* and *3* are looped and their resistance is found to be R_2; finally r_2 and r_3 are looped and their resistance is found to be R_3. We then have

$$r_1 + r_2 = R_1$$
$$r_1 + r_3 = R_2$$
$$r_2 + r_3 = R_3$$

Adding the equations and dividing by 2, we have

$$r_1 + r_2 + r_3 = \frac{R_1 + R_2 + R_3}{2}$$

Therefore

$$r_1 = \frac{R_1 + R_2 + R_3}{2} - (r_2 + r_3)$$

$$= \frac{R_1 + R_2 + R_3}{2} - R_3$$

Similarly

$$r_2 = \frac{R_1 + R_2 + R_3}{2} - R_2$$

and $$r_3 = \frac{R_1 + R_2 + R_3}{2} - R_1$$

The second terms of the last three formulas contain only known quantities and hence the required resistances may be readily calculated.

The resistance of nearly all field coils of dynamos may be measured by use of the Wheatstone bridge. Shunt field coils of 110 volt machines have a resistance of from about 5 ohms in large machines to 100 or 200 ohms in small machines. High voltage machines have a considerably higher shunt field coil resistance. The series coil of constant current dynamos have a resistance of 1 to 20 ohms. On account of the high self-induction of field coils the galvanometer key should not be depressed until some time after the battery circuit is closed.

The armature resistance of most machines may be measured by the bridge, but it is usually much more convenient to use the "fall of potential" method described below, measuring both current and voltage, and obtaining the resistance by simple division.

Locating Faults. The locating of faults in telegraph lines and cables often involves a number of measurements and considerable calculation. The nature of faults are so varied that one or two methods cannot be applied to all cases.

The kind of a fault which is easiest to locate is where the circuit is completely broken and the fault has no resistance. In this case the conductivity resistance of the wire to the fault may be measured, and dividing this by the conductivity resistance per mile gives the distance in miles to the fault.

The location of faults in dynamos is easily accomplished by the *drop or fall of potential method*. A current from an independent source is passed through the armature and connections, the armature being restrained from moving. The leads from a low reading voltmeter are then applied to different sections of the circuit. The reading of the voltmeter gives of course, the drop in volts in the section included between its terminals. For example, the voltmeter leads may be successively applied to all adjacent segments of the commutator. The potential difference between adjacent segments should be equal; thus a short circuit would be readily located by a decrease in the voltmeter reading. When the current is passed through the field coils, the potential difference at the terminals of each field coil should be nearly equal. A poor contact will be at once indicated by an increase in the reading.

If the current is taken from 110 volt mains, the shunt coils may be connected directly to them, but in testing the armature an additional resistance should be connected in series to prevent a short circuit. This extra resistance should be adjustable so that the current may be regulated. A water rheostat or bank of incandescent lamps serve the purpose very well.

Resistance of Batteries. A very convenient method of measuring the resistance of a cell or battery, is by means of an ammeter and voltmeter. The E. M. F. on open circuit is first measured by the voltmeter. Let this be E. The battery circuit is then closed through an ammeter and suitable resistance; the value of the resistance being such that the output will be equal to the value desired. The readings of the instruments then give the current I, and the E. M. F. on closed circuit e. The drop of potential in the battery is then equal to $E - e$, which is the number of volts necessary to drive this current through the battery. Therefore, by Ohm's law, the resistance of the battery is equal to $\frac{E - e}{I}$.

Another method requires the use of a low reading voltmeter and resistance box. The electromotive force E of the battery is first measured by the voltmeter when the circuit is open. A known resistance R is then connected in series with the cell and the E. M. F. again measured. This voltage will be less than before, as some E. M. F. is lost in the cell itself.

The drop in volts in the cell when the current is flowing is equal to $E - e$; the drop in the resistance R is equal to e, since this voltage is lost in the external circuit. Then if X is the resistance of the cell we have the proportion,

$$X : R :: E - e : e,$$

as the resistances are proportional to the drop in volts.

Example. — The E. M. F. of a Daniell cell on open circuit as measured by a voltmeter was found to be 1.08 volts. On closed circuit with an external resistance of 15 ohms, the E. M. F. was .90 volts. What was the internal resistance of the cell?

Solution. — Here $E = 1.08$, $e = .90$, and $R = 15$. Substituting in the preceding proportion, we have,

$$X : 15 :: 1.08 - .90 : .90.$$

Therefore, $X = 3$. **Ans. 3 ohms.**

MEASUREMENT OF ELECTROMOTIVE FORCE.

This is most easily accomplished by connecting the leads from a voltmeter to the points between which the potential difference is to be measured; the voltmeter forming a shunt circuit. Weston portable voltmeters are to be recommended for accuracy and permanency, the average error usually being less than .2 volt.

Potentiometer Method. This method is the standard for the accurate comparison of electromotive forces, and is used for checking standard cells against each other and for calibrating voltmeters.

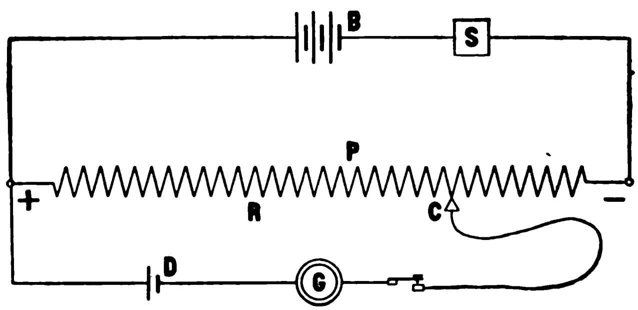


Fig. 25.

The connections are shown in Fig. 25. The potentiometer P consists of a number of coils all connected in series giving a high resistance. A sliding contact piece C is adjustable along P as in the slide wire bridge, and the resistance on either side of C may be read directly from a scale. A constant battery *B* having a greater E. M. F. than that to be measured, is connected to the ends of the resistance *P*, the positive pole of the battery being connected to the left-hand terminal of the potentiometer. The positive pole of the cell *D* to be tested, is also joined to the left-hand terminal. The negative terminal of the cell is connected through a galvanometer *G* and a key to the contact piece *C*. A resistance *S* is connected in series with the battery *B* in order to reduce the potential difference across *P* to any desired amount.

The determination is made as follows:

Before testing the cell *D* a standard cell of known E. M. F. is first inserted in its place, and *C* adjusted until there is no deflection of the galvanometer upon closing the key. The cell is connected so that its E. M. F. opposes that of the battery; therefore, when no current flows through the galvanometer, the E. M. F. of the cell must be equal and opposite to the potential difference between the point *C* and the terminal at the left. The resistance R^1 included between these points is proportional to the potential difference. The standard cell is then replaced by the cell *D*, and *C* again adjusted until there is no deflection of the galvanometer. Let the resistance included be *R*. As the E. M. F. of each cell is proportional to the resistance included, we have,

$$E.\ M.\ F.\ of\ cell : E.\ M.\ F.\ of\ standard\ cell :: R : R^1.$$

The values of R and R^1 are given directly by the potentiometer readings.

Condenser Method. A very convenient method is that in which a condenser is used. A condenser is first charged by a standard cell and then discharged through a ballistic galvanometer. The condenser is then charged by the cell to be tested and again discharged through the galvanometer. The E. M. F. of the cells are proportional to the deflections of the galvanometer.

E. M. F. of Alternating Currents. As the E. M. F. of alternating currents changes from positive to negative and from negative to positive many times a second, it is evident that the above methods which apply to direct currents cannot be adapted to alternating currents. Special forms of voltmeters and dynamometers are therefore necessary.

The electrostatic voltmeter is very largely used in alternating current work. As the force of attraction between two plates is the same whether one is positive and the other negative, or one negative and the other positive, it is evident that this voltmeter is equally well adapted for alternating or for direct currents.

The dynamometer is also used in alternating current work. For measuring E. M. F. the coils are given a high resistance or a high resistance is placed in series with them. The Weston alternating current voltmeter is of the dynamometer type. In this instrument the movable coil is mounted in bearings, the current being lead to and from the coil by watch springs as in the direct current voltmeter.

Calibration of Voltmeters. The errors in a voltmeter scale which is already graduated, are very accurately determined by use of the potentiometer. The connections, shown in Fig. 26, are similar to those in Fig. 25 required in measuring E. M. F. The

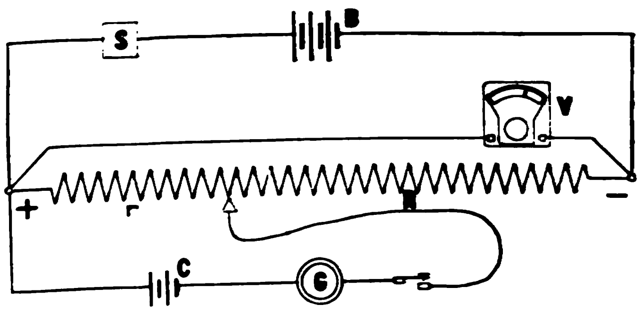


Fig. 26.

voltmeter V to be calibrated is connected across the ends of the potentiometer, which should have a resistance of at least 10,000 ohms. A constant battery B which must have an E. M. F. greater than that of the highest reading of the voltmeter is also connected to the potentiometer terminals. The adjustable resistance S is used to regulate the E. M. F. applied to the terminals of the potentiometer. Standard cells C, in series with a galvanometer are connected as shown, the positive pole of the cells and battery are both connected to the same potentiometer terminal. A resistance should be connected in series with the cells and galvanometer to prevent polarization during trial adjustments, and may be short circuited during the final adjustment.

To calibrate a voltmeter, S is first adjusted until a desired deflection of the voltmeter is obtained. The contact key or slider is then moved until such a point is found that closing the key causes no deflection of the galvanometer. The E. M. F. of the cells then exactly balances the potential difference between the slider and left-hand terminal. The resistances r and R on either side of the slider are then read from the instrument, and the *true* potential difference across the ends of the potentiometer is calculated as follows: The drop in volts in r is equal to the E. M. F. of the cells C. The drop in volts in $R + r$ is the total E. M. F. available. As the drop in volts is proportional to the resistance, we have

$$\text{total } E.\ M.\ F. : E.\ M.\ F. \text{ of } C :: R + r : r,$$

therefore

$$\text{total } E.\ M.\ F. = \frac{R + r}{r} \times E.\ M.\ F. \text{ of } C.$$

Example. — In calibrating a voltmeter the shunt S was adjusted to give a voltmeter reading of 27.8 volts. Two standard cells were used each having an E. M. F. of 1.435 volts. The total resistance of the potentiometer was 10,000 ohms, and when a balance was secured the value of r was 1,040 ohms. What correction should be applied to the voltmeter reading?

Solution. — In this case $R + r = 10{,}000$, $r = 1{,}040$ and E. M. F. of $C = 2 \times 1.435 = 2.87$. Substituting in the preceding formula,

$$\text{total } E.\ M.\ F. = \frac{10{,}000}{1{,}040} \times 2.87 = 27.6 \text{ volts (nearly)}.$$

The voltmeter reading is therefore too high by .2 volt.

Ans. — .2 volt.

By adjusting the shunt S the errors in various parts of the scale may be determined and a table of corrections made.

If it is desired to graduate the scale so as to give correct readings a slightly different method is employed. In such a case the apparatus is adjusted to give a potential difference of a certain number of volts at the terminals of the potentiometer, and the position taken by the pointer of the voltmeter is marked that number of volts. By succeeding adjustments other points are located along the scale, and this skeleton scale is then subdivided into smaller divisions. Suppose a reading of 10 volts is desired. By moving the slider, r is given such a resistance that $r : 10{,}000 :: 2.87 : 10$, assuming the total resistance to be 10,000 ohms and that the standard cells have an E. M. F. of 2.87 volts. The value of r is then made equal to 2,870 ohms. The shunt S is then adjusted until there is no deflection of the galvanometer, which gives a potential difference at the voltmeter terminals of 10 volts. Similarly the correct position of the pointer for 20, 30, 40, etc., volts may be determined.

It is desirable to use several standard cells in series at C, as this gives a close average value and also gives larger readings on the potentiometer. When very accurate work is required the standard cells should be placed in a water or oil bath and a correction for temperature made if necessary.

The above method of calibrating voltmeters is that used in the laboratory for calibrating standard instruments. Station voltmeters may then be calibrated by direct comparison with such standards.

The Clark Standard Cell. The *absolute unit* of E. M. F. is that developed by a conductor when it cuts one line of force per second, and the *practical unit* or volt is equal to 10^8 absolute units. In order to have some working standard, the volt is defined in terms of the Clark cell. In this cell the negative element is a rod of pure zinc in a solution of zinc sulphate, and the positive element is mercury in a paste of mercurous sulphate and zinc sulphate solution. This cell is the international standard of E. M. F. and if the standard directions for setting it up are followed, the E. M. F. of 1.434 true volts will be obtained if the temperature is 15° C. The E. M. F. decreases slightly with an increase of temperature, and if the cell is at any other temperature, the correct E. M. F. is given by the formula $E = 1.434 - .0011\ (t - 15)$, where t is the temperature in degrees Centigrade.

There are several other forms of cells used as standards, one of the most reliable being the Carhart-Clark cell, which is illustrated in Fig. 27. Above a layer of mercury in the bottom of the cell is the mercurous sulphate and zinc sulphate solution. A piece of cork separates this from a solution of zinc sulphate above it, in which the zinc is immersed. The strength of this solution is determined by the fact that it is saturated at 0° C. Contact is made with the mercury in the bottom of the cell by a platinum wire passing down through a small glass tube. The E. M. F. of this cell at 15° C. is 1.442 volts, the E. M. F. at other temperatures being given by the formula

$$E = 1.442 \left\{ 1 - .00039\,(t - 15) \right\}$$

In the figure a Centigrade thermometer is shown permanently attached to the cell.

In using a standard cell great care should be taken that only very small currents are allowed to pass through it and then only for a short period. To prevent polarization and a consequent decrease of E. M. F. a high resistance should be connected in series, except for final adjustments in zero methods. A short circuit is likely to permanently injure a cell.

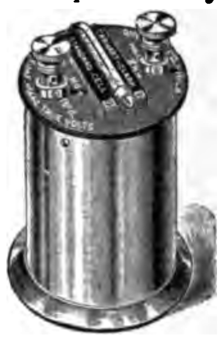


Fig. 27.

MEASUREMENT OF CURRENT.

One of the most accurate and universally applicable methods of measuring current strength is to measure the potential difference across a known resistance through which the current is passing. The value of the current is then given by the formula $I = \frac{E}{R}$. This method is well adapted for the measurement of very large or very small currents.

The simplest method of measuring current strength is by the insertion of an ammeter in the circuit. Ammeters are usually less reliable than voltmeters, but the importance of obtaining current strength accurately is usually less than that of E. M. F.

Alternating currents may be measured by the dynamometer, current balance, measurement of E. M. F. across a known resistance, and by some forms of ammeters.

Ammeter Calibration. A very convenient method of determining the accuracy of ammeters is by measuring the potential difference across a known resistance in the circuit. The connections are shown in Fig. 28. In circuit with the source of E. M. F. is the ammeter A, the known resistance R, and the resistance r

for varying the strength of the current. A standard voltmeter *V* which has been accurately calibrated is connected across the terminals of the known resistance. Dividing the voltmeter reading by the value of *R*, determines the current strength and error of the ammeter.

Ammeters can also be very accurately calibrated by direct comparison with Thomson's current balance.

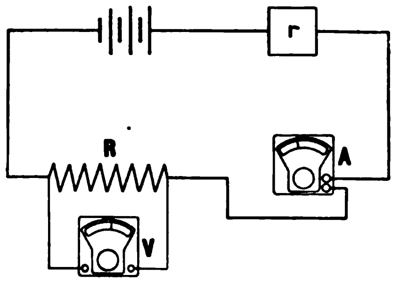


Fig. 28.

MEASUREMENT OF ENERGY.

The wattmeter is used to indicate the power consumed in a circuit. The dynamometer of the Siemens type is one of the most common forms of wattmeter. The high resistance coil is shunted across the part of the circuit in which the energy consumed is to be measured, and the low resistance coil connected in series.

With direct currents the energy consumed in watts is usually obtained from multiplying the reading of a voltmeter shunted across the terminals, by the reading of an ammeter inserted in the circuit.

MEASUREMENT OF QUANTITY.

As the unit of quantity is the ampere second or coulomb, it may be measured by determining the current strength for a certain length of time.

One method of measuring quantity which is largely used depends on the chemical action of a current when passed through an electrolyte, the latter being decomposed by the current. The amount of this decomposition is directly proportional to the strength of the current and to the time. Therefore the quantity of electricity will depend upon the amount of chemical decomposition. The average current may be determined by dividing the quantity by the time. Instruments arranged for measuring quantity or current strength on this principle are termed voltameters.

The Edison *chemical meter* is the voltameter most generally used. This consists of a cell containing a solution of zinc sulphate, and two zinc plates of a certain size at a fixed distance apart. A low resistance shunt of German silver is connected in the main circuit and the cell is connected about this. If the ratio of the cell resistance to that of the shunt is constant, then a certain fraction of the total current will pass through the cell from which the whole may be determined. This ratio is about 1000. As the resistance of the cell decreases with rise of temperature, a resistance of copper wire is inserted in series with it. The increase in resistance of this with rise of temperature, just equals the decrease in the resistance of the cell. The ratio of the resistances is thus maintained constant. As the current passes from one zinc plate to the other through the electrolyte, the positive plate gradually goes into solution and loses in weight and the negative plate gradually gains in weight. By weighing the plates before and after the passage of the current the quantity of electricity passed may be determined. Usually the weight of the positive plate only is taken, and its lost weight multiplied by a constant to give the number of coulombs or ampere-hours.

The Forbes meter depends upon the heating effect of a current to record the number of ampere-hours. The current is passed through a number of fine wires connected in parallel. The heating of these causes a rising current of warm air and this rotates a spindle carrying light mica vanes. The number of ampere-hours is determined from the number of revolutions of the spindle.

If the potential of the circuit is constant the number of watt-hours is found from the ampere-hours if the latter is multiplied by the voltage of the circuit.

MEASUREMENT OF CAPACITY.

Capacity and its measurement becomes of considerable importance in the case of submarine and underground cables. Such cables actually become condensers, the internal wire forms the inner coating, the water the outer coating and the insulation forms the dielectric between them. This presence of capacity in cables makes it necessary to charge them before a signal is indicated at the distant end, and thus causes retardation in the transmission of signals and also enfeebles the strength of the current at the distant station.

Ordinary condensers may be charged or discharged almost instantaneously. The charging and discharging of cables however, requires so much time that the accurate measurement of their capacity is very difficult. In discharging, a cable yields most of its charge at first, and then gradually gives up the remainder.

Direct Deflection Method. In this method of measuring capacity, which is the simplest and most generally employed, a standard condenser is first charged by a battery and then discharged through a ballistic galvanometer. The condenser of unknown capacity is then similarly charged and discharged. The capacities of the two condensers are proportional to the galvanometer deflections.

Example. — A condenser of .3 microfarad capacity was charged by a battery and when discharged through a galvanometer gave a deflection of 103 scale divisions. A condenser of unknown capacity was then charged by the same battery and on discharge gave a deflection of 128 divisions. What was the unknown capacity?

Solution. — As the capacities are proportional to the deflections we have the proportion,

$$x : .3 :: 128 : 103$$

$$\text{or } x = \tfrac{128}{103} \times .3 = .37 +$$

Ans. .37 + microfarad.

Divided Charge Method. This method gives more accurate results than the preceding and is often used in measuring the capacity of long cables. The connections are shown in Fig. 29. The key k is first depressed, charging a condenser C of known capacity. The key k is then opened and the key K raised, discharging the condenser through the galvanometer G, giving a deflection D. C is then again charged, k opened and K depressed. This connects

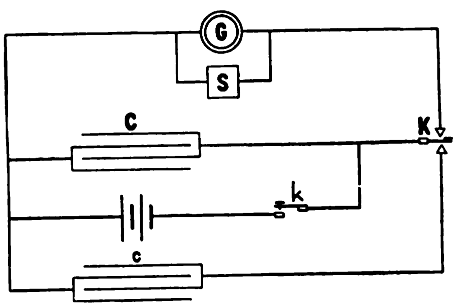


Fig. 29.

the standard condenser with the condenser c of unknown capacity, and shares part of its charge with the same. The division of charge is proportional to the capacities. By raising K the condenser C is again discharged through the galvanometer, giving a deflection d. As the deflections are proportional to the charge of C in each case, the capacity of C is to that of c as the first deflection D is to the decrease in deflection which represents the charge of c, that is,

$$C : c :: D : D - d,$$

therefore,

$$c = \frac{D - d}{D} \times C.$$

Bridge Method. In this method the capacities of a standard and of any other condenser are balanced in the arms of a bridge. Fig. 30 illustrates the necessary connections. The standard C and that of unknown capacity c, form two arms of the bridge, and the adjustable resistances R and r complete it When the key K is raised, current flows from the battery and charges the

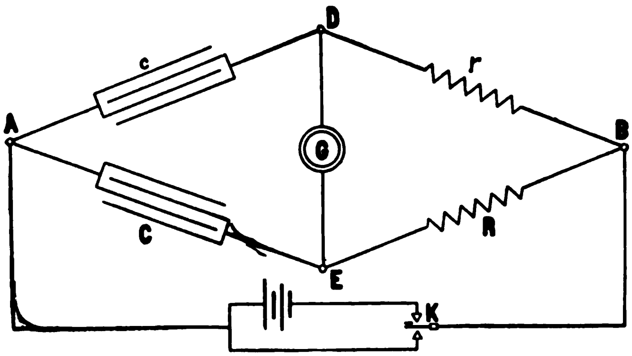


Fig. 30.

condensers; on depressing the key the condensers are discharged. The resistances r and R are adjusted until during charging and discharging there is no deflection of the galvanometer. The potential at D and E will then be the same, and the condensers are there fore charged under the same potential; the quantity of electricity required to charge them will then be proportional to their capacities. When there is no deflection of the galvanometer in charging or discharging, the drop in the resistances r and R must be the same. Suppose the capacity of c to be larger than that of C: then in charging, the current passing through r must be greater than that through R. As the drop is proportional to the product of current and resistance; then in order to have the same drop in r as in R if a larger current flows through r its resistance must be less. The capacities of the condensers are therefore inversely as these resistances, or

$$c : C :: R : r.$$

Example. — With condensers connected as shown in Fig. 30, it was found that there was no deflection of the galvanometer when r was 2,700 ohms and R 7,300 ohms. The capacity of the standard condenser C was .2 microfarad. What was the capacity of c?

Solution. — Substituting in the preceding proportion, we have,

$$c : .2 :: 7{,}300 : 2{,}700,$$

therefore $c = .54$. Ans. .54 microfarad.

Thomson's Method. If two condensers are charged with

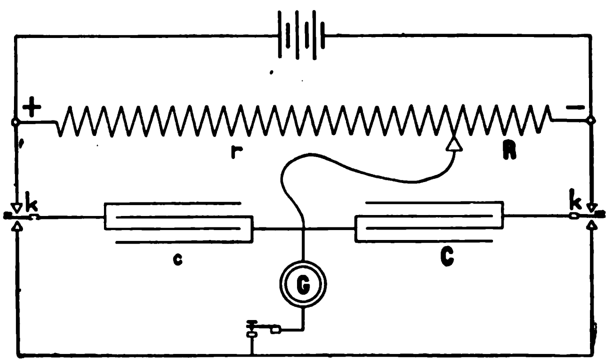
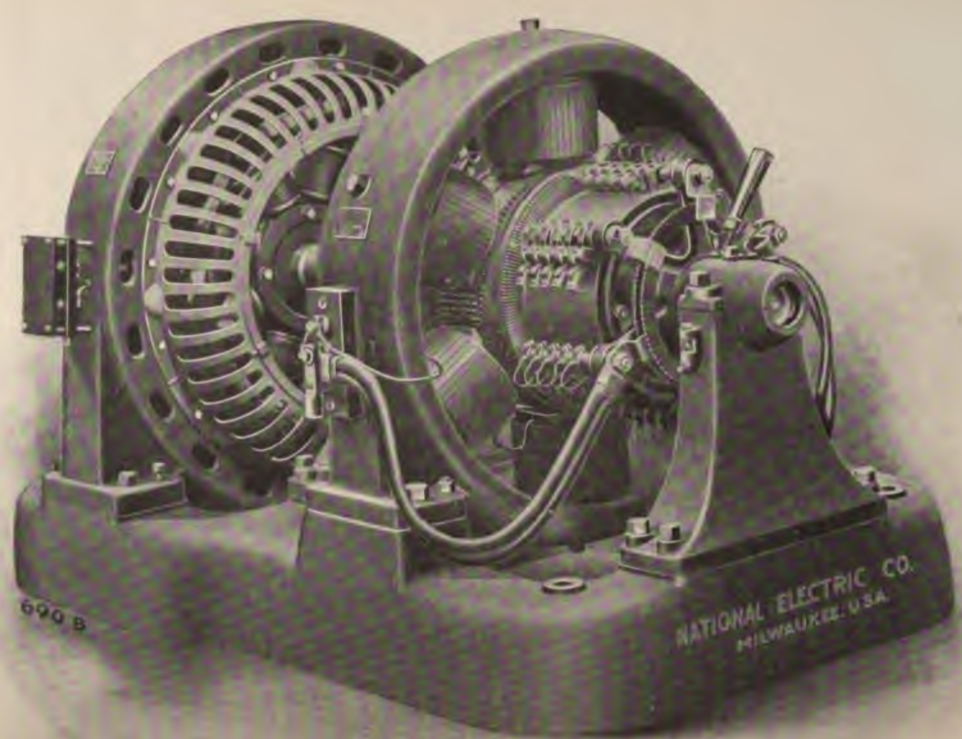


Fig. 31.

equal quantities of electricity and then discharged by connecting them in series + to — and — to +, the two charges will exactly neutralize each other and no resultant charge will remain. To charge two condensers of unequal capacity with equal quantities of electricity requires a higher E. M. F. at the terminals of the smaller condenser, that is, the E. M. F. applied at the terminals must be inversely as the capacities. If the ratio of the E. M. F.'s is determined, then the ratio of the capacities of the condensers is also obtained. These principles are involved in Thomson's method.



"NATIONAL" MOTOR-EXCITER SET.

50 K.W. 900 R.P.M.

ELECTRIC WIRING.

INSTALLING THE DYNAMO.

Dynamos should be located in a dry place so situated that the surrounding atmosphere is cool. If the surrounding air is warm, it reduces the safe carrying capacity of the machine and is likely to allow such temperature to rise in the machine itself as to burn out either armature or field, or both. A dynamo should not be installed where any hazardous process is carried on, nor where it would be exposed to inflammable gases or flying combustible materials, as the liability to occasional sparks from the commutator or brushes might cause serious explosions.

Wherever it is possible, dynamos should be raised or insulated above the surrounding floor, on wooden base frames, which should be kept filled to prevent the absorption of moisture, and also kept clean and dry. When it is impracticable to insulate a dynamo on account of its great weight, or for any other reason, the Inspection Department of the Board of Fire Underwriters having jurisdiction may, in writing, permit the omission of the wooden base frame, in which case the frame should be permanently and effectively grounded. When a frame is grounded, the insulation of the entire system depends upon the insulation of the dynamo conductors from the frame, and if this breaks down the system is grounded and should be remedied at once.

Grounding Dynamo Frames can be effectually done by firmly attaching a wire to the frame and to any main water pipe inside the building. The wire should be securely fastened to the pipe by screwing a brass plug into the pipe and soldering the wire to this plug. When the dynamo is direct driven, an excellent ground is obtained through the engine coupling and the piping of the engine and boiler.

Wherever high-potential machines have their frames grounded, a small board walk should be built around them and raised above the floor, on porcelain or glass insulators, in order that the dynamo tender may be protected from a shock when adjusting brushes or working about the machine.

Sufficient space should be left on all sides of the dynamo and especially at the commutator end, so that there may be ample room for removing armatures, commutators, or any other parts at any time.

Circuit Breakers and Fuses. Every constant-potential generator should be protected from excessive current by a safety fuse or equivalent device of approved design, in each wire lead, such as a circuit breaker. The latter is preferable, on account of its being immeasurably more accurate and convenient for resetting. Such devices should be placed on or as near as possible to the dynamo. When the needs of the service make these devices impracticable, the Inspection Department having jurisdiction may, in writing, modify the requirements.

The best practice is to place the fuses on the dynamo itself, and the circuit breakers on the switchboard.

Waterproof Covers should be provided for every dynam and placed over each machine as soon as it is shut down. Negligence in this matter has caused many an armature and field coil to burn out, as only a few drops of water are necessary to cause a short circuit as soon as the machine is started up again, which might do many dollars' worth of damage, to say nothing of the inconvenience caused by shutting off light or power when it is most needed, and for an indefinite length of time.

Name-Plates. Every dynamo should be provided with a name-plate, giving the maker's name, the capacity in volts and amperes, and the normal speed in revolutions per minute. This will show exactly what the machine was designed for, and how it should be run.

Wiring from Dynamos to switchboards should be in plain sight or readily accessible, and should be supported entirely upon non combustible insulators, such as glass or porcelain; in no case should any wire come in contact with anything except these insulators, and the terminals upon the dynamos and switchboards. When it becomes necessary to run these wires through a wall or floor, the holes must be protected by some approved non-combustible insulating tube, such as glass or porcelain, and in every case the tube must be fastened so that it shall not slip or pull out. Sections of any tubing, whether armored or otherwise, that are chopped off for this purpose, should not be used. All wires for dynamos and switchboard work should be kept so far apart that there is no liability of their coming in contact with one another, and should be covered with non-inflammable insulating material sufficient to prevent accidental contact, except that bus bars may be made of bare metal so that additional circuits can be readily attached. Wires must have ample carrying capacity, so as not to heat with the maximum current likely to flow through them under natural conditions. (See "Capacity of Wires Table," page 37.) So much trouble in past years has arisen from faulty construction of switchboards, and the apparatus placed upon them, that strict requirements have been necessarily adopted by engineers as well as insurance inspectors, and the following suggestions are recommended by the latter:

The Switchboard should be so placed as to reduce to a minimum the danger of communicating fire to adjacent combustible material, and, like the dynamo, should be erected in a dry place and kept free from moisture. It is necessary that it should be accessible from all sides when the wiring is done on the back of the board, but it may be placed against a brick or stone wall when all wiring is on the face.

The board should be constructed wholly of non-combustible material, but when this is impossible a hard-wood board made in skeleton form, and well filled to prevent absorption of moisture, is considered safe. Every instrument, switch or apparatus of any kind placed upon the switchboard should have its own non-combustible insulating base. This is required of every piece of apparatus connected in any way with any circuit. If it is found impossible to place the resistance box or regulator (which should, in every case, be made entirely of non-combustible material) upon the switchboard, it must be placed at least one foot from combustible material or separated therefrom by a non-inflammable, non-absorptive insulating material. A slate slab is preferable. Special attention is called to the fact that switchboards should not be built down to the floor, nor up to the ceiling, but a space of at least ten or twelve inches should be left between the floor and the board, and from eighteen to twenty-four inches between the ceiling and the board, in order to prevent fire from communicating from the switchboard to the floor or ceiling, and also to prevent space being used for storage of rubbish and oily waste.

Lightning Arresters should be attached to each side of every overhead circuit connected with the station.

It is recommended to all electric light and power companies that arresters be connected at intervals over systems in such numbers and so located as to prevent ordinary discharges entering (over the wires) buildings connected to the lines. They should be located in readily accessible places away from combustible materials, and as near as practicable to the point where the wires enter the building.

Station arresters should generally be placed in plain sight on the switchboard. In all cases, kinks, coils and sharp bends in the wires between the arresters and the outdoor lines should be avoided as far as possible. Arresters should be connected with a thoroughly good and permanent ground connection by metallic strips or wires having a conductivity not less than that of a No. 6 B. & S. copper wire, and running as nearly as possible in a straight line from the arresters to the earth connection.

Ground wires for lightning arresters should not be attached to gas pipes within the buildings.

It is often desirable to introduce a choke coil in circuit between the arresters and the dynamo. In no case should the ground wire from a lightning arrester be put into iron pipes, as these would tend to impede the discharge.

Unless a good, damp ground is used in connection with all lightning arresters, they are practically useless. Ground connections should be of the most approved construction, and should be made where permanently damp earth can be conveniently reached. For a bank of arresters such as is commonly found in a power house, the following instructions will be found valuable: First, dig a hole six feet square directly under the arresters, until permanently damp earth has been reached; second, cover the bottom of this hole with two feet of crushed coke or charcoal (about pea size); third, over this lay twenty-five square feet of No. 16 copper plate; fourth, solder at least two ground wires, which should not be smaller than No. 6, securely across the entire surface of the ground plate; fifth, now cover the ground plate with two feet of crushed coke or charcoal; sixth, fill in the hole with earth, using running water to settle.

All lightning arresters should be mounted on non-combustible bases and be so constructed as not to maintain an arc after the discharge has passed; they should have no moving parts.

Testing of Insulation Resistance. All circuits except those permanently grounded should be provided with reliable ground detectors. Detectors which indicate continuously and give an instant and permanent indication of a ground are preferable. Ground wires from detectors should not be attached to gas pipes within the building.

Where continuously indicating detectors are not feasible, the circuits should be tested at least once per day.

Data obtained from all tests should be preserved for examination.

Storage or Secondary Batteries should be installed with as much care as dynamos, and in wiring to and from them the same precautions and rules should be adopted for safety and the prevention of leaks. The room in which they are placed should be kept not only dry, but exceptionally well aired, to carry off all fumes which are bound to arise. The insulators for the support of the secondary batteries should be glass or porcelain, as filled wood alone would not be approved.

Care of Dynamos. A few suggestions as to the care of the dynamo, as well as its installation, may be of value; and one of the important points under this head is that the driving power should have characteristics of steadiness and regularity of speed, and should always be sufficient to drive the dynamo with its full load, besides doing the other work which it may be called upon to sustain. Unsatisfactory results are always obtained by attempting to run a dynamo on an overloaded engine.

Wooden bed-plates are supplied, when ordered, for all dynamos, except in the largest and direct-connected machines.

Most machines are fitted with a ratchet and screw bolt, so that they may be moved backward or forward on the bed-plate in a direction at right angles to the armature shaft. By this means the driving belt can be tightened or loosened at will, while the machine is in operation. Care should be taken in tightening the belt not to bind the bearings of the armature and force the oil from between the surfaces of the shaft and boxes. Such practice will inevitably cause heating of the bearings and consequent injury.

Machines are usually assembled, unless ordered otherwise, so that the armature revolves clock-wise when the observer faces the pulley end of the shaft. All bipolar dynamos, however, may be driven in either direction by reversing the brushes and changing field connections.

The machine is provided with a pulley of the proper size to transmit the power demanded, and a smaller one should not be substituted unless approval be obtained from the makers.

When driving from a countershaft, or when belted directly to the main shaft, a loose pulley or belt holder should be used, to admit of starting and stopping the dynamo while the shafting is running.

Belts. A thin double or heavy single belt should be used, about a half inch narrower than the face of the pulley on the dynamo. An endless belt, one without lacing, gives the greatest steadiness to the lights.

All bolts and nuts should be firmly screwed down. All nuts which form part of electrical connections should receive special attention.

The copper commutator brushes are carefully ground to fit the commutator, and they should be set in the holders so as to bear evenly upon its surface. On machines where two or more brushes are supported on one spindle, the brushes on the same side of the commutator must be set so that they touch the same segments in the same manner. The brushes on the other side of the commutator must be set to bear on the segments diametrically opposite. When the brushes are not so set it is impossible to run the machine without sparking. A convenient method of determining the proper bearing point for the brushes is to set the toe of one brush at the line of insulation, dividing two segments of the commutator; then count the dividing lines for one-half the way around the surface, and set the other brush or brushes at the line diametrically opposite the first. Thus, on the forty-four segment commutator, after setting the tip of one brush at a line of insulation, count around twenty-three lines, setting the other brush at the twenty-third line, thus bringing the tips directly opposite each other. The angle which the brushes form with the surface of the commutator should be carefully noted, and the brushes should not be allowed to wear so as to increase or decrease this angle. Careless handling of the machine is at once indicated by the brushes being worn either to a nearly square end, or to a long taper in which the forward wires of the brush far outrun the back or inside wires. Either condition will inevitably be attended with excessive wear of both commutator and brushes.

After copper brushes are set in contact with the commutator, the armature should never be rotated backward. If it is required to turn the armature back, raise the brushes from the commutator by the thumb screw on the holder provided for that purpose, before allowing such rotation. When starting a machine, it is always better to let the brushes down upon the commutator after the machine has started, rather than before, except when carbon brushes are used.

Bearings. See that the bearings of the machine are clean and free from grit, and that the oil reservoirs are filled with a good quality of lubricating oil. The oil reservoirs should always be examined before starting, and all loose grit removed. After starting the machine, the oil should be all drawn off at the end of each day's run for the first three or four days, after which it may be assumed that any remaining grit has been carried off with the oil, and it will only be necessary to add a little fresh oil once in seven or ten days.

Starting Up a Dynamo or Motor. Fill the oil reservoirs and see that the automatic oiling rings are free to move. In the case of dynamos fitted with oil cups, start the oil running at a moderate rate. Too little oil will result in heating and injury of the bearings, but, on the other hand, excessive lubrication is unnecessary, wasteful and sometimes productive of harm.

When the dynamo is ready to be started, place the driving belt on the pulley on the armature shaft, and then slip it from the loose pulley or belt holder on to the driving pulley on the countershaft. Tighten the belt by means of the ratchet on the bed-plate, just sufficiently to keep it from slipping. Care should be taken not to put more pressure than is necessary on new bearings; carelessness in this respect is often followed by heating of the boxes, and possible permanent injury.

The brushes may now be let down upon the commutator, and the magnets will be slowly energized. Move the brushes slowly backward or forward by means of the yoke handle until there is no sparking at the lower brushes. Clamp the yoke in this position. If the top brushes then spark, move them slightly, one at a time, forward or backward in the brush holder until their non-sparking point is found.

The spring pressure exerted upon the commutator brushes should be just sufficient to produce a good contact without causing cutting. If the brushes cut, the commutator must be smoothed by the use of sandpaper, not *emery cloth*.

The dynamo should run without load, at the speed given by the manufacturer, and this speed should be uniformly maintained under all conditions. In the case of incandescent dynamos, any increase of speed above that given, shortens the life of the lamps while a variation below causes unsatisfactory lights.

Before the load is put on, the dynamo should be tested for polarity. This can be done by holding a small pocket compass near the field or pole piece. If the dynamo is connected to be run in multiple with another machine and happens to be polarized wrong, it can be given the right polarity by lifting the brushes from the commutator, closing the field switch and then closing the double-pole switch used to throw it in multiple with the other machine, which is supposed to be now running. After the current has been allowed to pass through the fields for a few moments, the double-pole switch can be thrown open, and if a test with the compass is again made the polarity will be found to be right, and the dynamo is ready to be started in the usual manner.

In starting for the first time a bipolar dynamo which is to be run in multiple with a spherical armature dynamo, the above instructions should always be followed.

If the dynamo is to be used in series with another on the three-wire system, and is found to be polarized wrong, it can be given the right polarity by making a temporary connection from the positive brush of the new machine to the positive brush of the machine already in operation; and also a temporary connection from negative brush to negative brush, having first raised the brushes from the commutator and closed the field switch. Keep this connection for a few minutes, then open the field switch and break the temporary connections.

Another test with the compass will show that the polarity of the machine is now correct, and the dynamo is ready to be started in the usual manner.

Assuming that the lamps and lines are all ready, the following precautions must be observed when starting the dynamo:

Be very careful that the brushes are properly set and diametrically opposite each other, as explained before.

Be sure that all connections are securely made, and all nuts on the connection boards firmly set.

In cases where two or more dynamos are connected in multiple by the use of the equalizing connection, care should be taken that the circuit wires from both positive brushes are connected to the same side of the main line, while those from the negative are connected to the other side.

A neat arrangement of the equalizing connection can be made by using triple-pole switches on the switchboard, instead of double-pole switches, and making the equalizing connections through the center pole of the switch, instead of running a cable direct from one dynamo to the other. This method is especially desirable where three or more dynamos are run in multiple.

When dynamos are connected in series, as in the cases where the three-wire system is in use, the leading wire from the positive brush of one machine is connected to the negative brush of the other. The other two brushes (negative and positive) are connected to the main wire on the outside of the system, while the third or center wire is connected to the conductor between the two dynamos.

Dust or Gritty Substances. All insulations should be carefully cleaned at least once a day.

If any of the connections of the machine become heated, examination will show that the metal surfaces are not clean or not in perfect contact. Avoid the use of water or ice on the bearings in case of accidental heating, as the water may get to the armature and injure the insulation.

The Commutator should be kept clean and allowed to polish or glaze itself while running. No oil is necessary, unless the brushes cut, and then only at the point of cutting. A cloth slightly greased with vaseline is best for the purpose. Never use sandpaper on the commutator without first lifting the brushes. Otherwise the grit will stick to the brushes and cut the commutator.

Brushes. Care should be taken to keep copper commutator brushes in good shape, and not to allow them to be worn out of square; that is, too much to one side, so that the end is not worn at right angles to the lateral edges.

When the machine is not running, the brushes should always be raised from the commutator. The brushes should be kept carefully cleaned, and no oil or dirt allowed to accumulate upon them. This can be done by washing them occasionally in benzine or in a hot solution of soda ash.

Manufacturers usually furnish a gauge, which should be used occasionally to test the wearing of the brushes. If they are found to be worn either too flat or too blunt, they should be filed in proper shape, or, better still, ground on a grindstone. Carbon brushes require less care. Spindles upon which the brush holders are arranged to slide should be cleaned with emery cloth often enough to prevent tarnishing or the collection of dirt, which might cause heating by impairing the electrical connection.

Brush holders that can be moved laterally on the spindle by which they are supported, should be so arranged that the top and bottom brushes will bear on different parts of the length of the commutator, for the purpose of distributing the wear more uniformly.

In case of a **hot box** the most natural thing to do is to shut the machine down, but this should never be done until the following alternatives have been tried and failed:

First—Lighten the load.

Second—Slacken the belt.

Third—Loosen the caps on the boxes a little.

Fourth—Put more oil in bearings.

Fifth—If all the above fail to remedy the heating, use a heavy lubricant, such as vaseline or cylinder oil. Should the heating then diminish, the shaft must be polished with crocus cloth and the boxes scraped at the end of the day.

Sixth—Under no conditions put ice upon the bearing, unless you are perfectly familiar with such a procedure.

Seventh—If it is absolutely necessary to shut down, get the belt off as soon as possible, keeping the machine revolving meanwhile in order to prevent sticking, and at the same time take off the caps of the bearings. Do not stop the flow of oil to the bearings. When the caps have been taken off, stop the machine and get the linings out immediately, and allow them to cool in the air. Do not throw the linings into cold water, as it is liable to spring them.

Scraping should be done only by an experienced person, otherwise the linings may be ruined. Polish the shaft with crocus cloth, or, if badly cut, file with a very fine file, and afterwards polish with crocus.

Wipe the shaft, as well as the boxes, very carefully, as perhaps grit has been the cause of the hot box. Inspect the bearings; see that they are in line, that the shaft has not been sprung, and that the oil collar does not bear against the box.

Oily Waste should be kept in approved metal cans (made entirely of metal, with legs raising them at least three inches above the floor and with self-closing covers), and removed daily.

A competent man should always be kept on duty where generators are operating.

THE INSTALLATION OF MOTORS.

All motors should be insulated on floors or base frames, which should be kept filled to prevent absorption of moisture; also they should be kept clean and dry. Where frame insulation is impracticable, the Inspection Department having jurisdiction may, in writing, permit its omission, in which case the frame should be permanently and effectively grounded.

A high-potential machine which on account of great weight or for other reasons cannot have its frame insulated, should be surrounded with an insulated platform. This may be of wood, mounted on insulating supports, and so arranged that a man must stand upon it in order to touch any part of the machine.

The leads or branch circuits should be designed to carry a current at least fifty per cent greater than that required by the rated capacity of the motor, to provide for the inevitable overloading of the motor at times, without over-fusing the wires.

The motor and resistance box should be protected by a cut-out or circuit breaker, and controlled by a switch, the switch plainly indicating whether "on" or "off." Where one-fourth horse power or less is used on low-tension circuits a single-pole switch will be accepted. The switch and rheostat should be located within sight of the motor, except in cases where special permission to locate them elsewhere is given, in writing, by the Inspection Department having jurisdiction.

In connection with motors the use of circuit breakers, automatic starting boxes and automatic under-load switches is recommended, wherever it is possible to install them.

Motors should not be run in series, multiple, or multiple-series, except on constant-potential systems, and then only by special permission of the Inspection Department having jurisdiction.

Like generators, they should be covered with a waterproof cover when not in use, and if necessary, should be inclosed in an approved case.

Motors, when combined with ceiling fans, should be hung from insulated hooks, or there should be an insulator interposed between the motor and its support.

Every motor should be provided with a name-plate, giving the maker's name, the capacity in volts and amperes, and the normal speed in revolutions per minute.

One rule at all times to be remembered in starting and stopping motors is, *Switch first, rheostat last,* which means, in starting, close the switch first, and then gradually cut out all resistance as the motor speeds up, and to stop the motor open the switch first and then cut in all the resistance of the rheostat which is in series with the motor armature.

When starting any new motor for the first time, see that the belt is removed from the pulley and the motor started with no load. Never keep the rheostat handle on any of its coils longer than a moment, as they are not designed to regulate the speed of the motor but to prevent too large a flow of current into the armature before the latter has attained its full speed.

Fig. 1 shows a rheostat which is designed to protect automatically the armature of a motor. The contact arm is fitted with a spring which constantly tends to throw the arm on the "off point" and open the circuit, but is prevented from so doing, while the motor is in operation, by the small electro-magnet, shown on the face of the rheostat, which consists of a low-resistance coil connected in series with the field winding of the motor. This magnet holds the contact arm of the rheostat in the position allowing the maximum working current to flow through the armature while it is in operation.

If, for any reason, the current supplied to the motor be momentarily cut off, the speed of the armature generates a counter current which also tends to hold the arm in position as long as there is any motion to the motor armature; but as soon as the armature ceases to revolve, all current ceases to flow through the electro-magnet, thereby releasing the rheostat handle, which flies back to the "off point," as shown in the illustration, and the motor armature is out of danger. Such a device is of great value where inexperienced men have to handle motors, and are unaware that the first thing to be done when a motor stops, for any reason whatever, is to open the circuit, and then cut in all the resistance in the rheostat to prevent too large an in-rush of current when the motor is started up again.

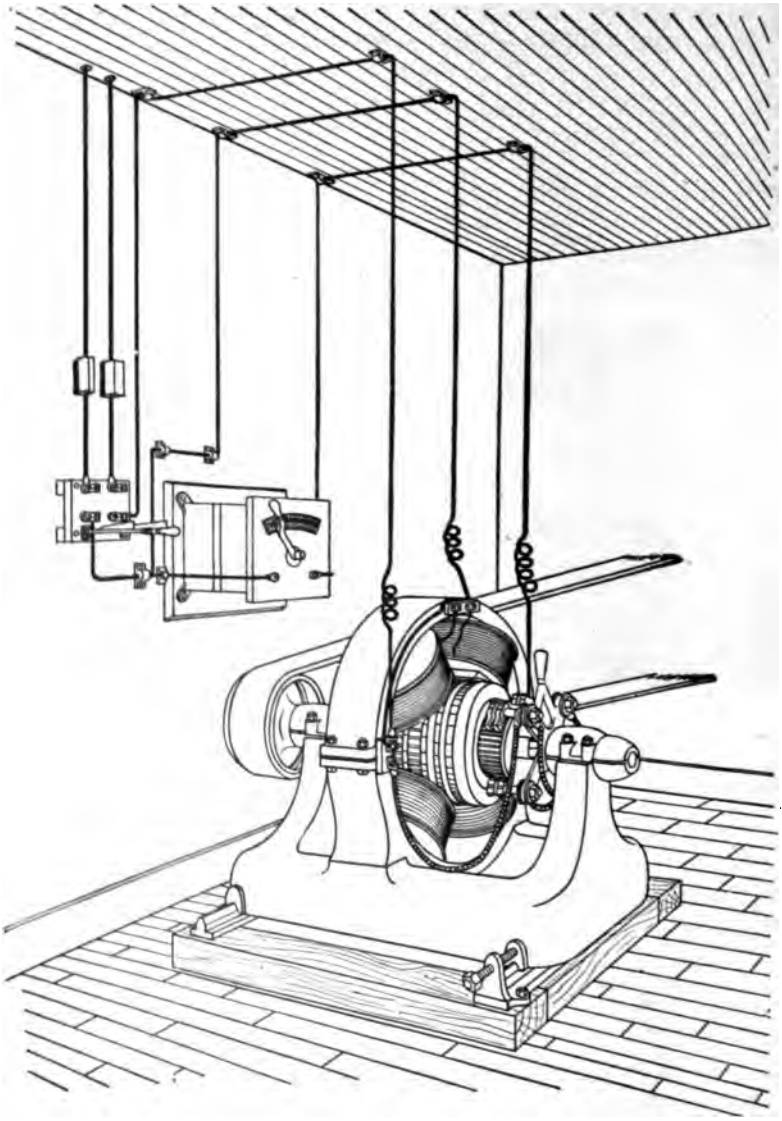


Fig. 1.

An approved installation in every detail; wiring connections for shunt-wound 4-pole motor, using double-pole fuse cut-out instead of circuit breaker.

The Circuit Breaker for under and over loads is also a most valuable protection in such cases.

Motor Wiring Formulæ—(Direct Current). To find the size of wire, in circular mils, required to transmit any power any distance at any required voltage and with any required loss, we have the following formula. Having found the required number of circular mils, it is advisable to add 50 per cent more for safety.

e = potential of motor. d = distance from generator to motor.
v = volts lost in lines. k = efficiency of motor.
10.8 = resistance in ohms of 1 foot of 97 per cent pure copper wire one mil in diameter.

$$\text{c.m.} = \frac{\text{h. p. of motor} \times 746 \times 2d \times 10.8}{e \times v \times k}$$

To find size of wire from c.m., see table, page 37.

AVERAGE MOTOR EFFICIENCY.

1 h. p.	75 per cent
3 h. p.	80 per cent
5 h. p.	80 per cent
10 h. p. and over	90 per cent

For Most Cases—(Small Installations). The table and examples worked out on pages 38, 39 and 40 will give the desired results without the above formulæ.

To find current required by a motor when the horse power, efficiency and voltage are known, use the following formula:

Let C = current to be found. H. P. = horse power of motor.
E = voltage of motor circuit. K = efficiency of motor.

$$C = \frac{\text{H. P.} \times 746 \times 100}{E \times K}$$

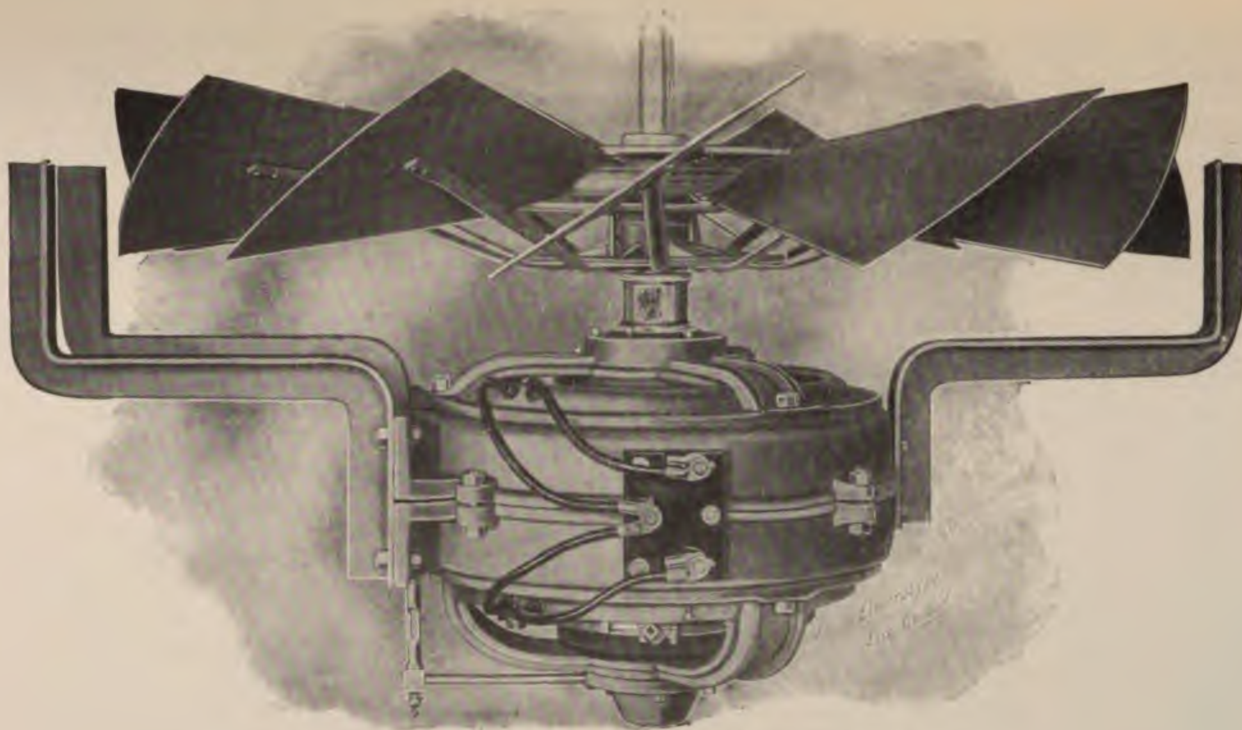
Or, when possible, use table I.

By adding the volts indicated in table II. to the voltage of the lamp or motor, the result shows the voltage at the dynamo for losses indicated. Thus 10 per cent on 110-volt system is: 12.22 volts added to 110 equal 122.22, showing that the dynamo must generate 122.22 volts for a 10 per cent loss.

TABLE I.

Amperes Per Motor.

H. P.	Per Cent.	Watts	THE TOP ROW INDICATES VOLTS. 50	75	110	220	400	500	600	800	1000	1200
¾	75	746	14.9	9.94	6.79	3.38	1.86	1.48	1.24	.93	.746	.62
1½	75	1492	29.8	19.8	13.56	6.78	3.73	2.98	2.48	1.86	1.492	1.24
3	80	2797	55.9	37.2	25.4	12.7	6.99	5.59	4.66	3.49	2.797	2.33
5	80	4662	93.2	62.1	42.3	21.1	11.65	9.32	7.77	5.82	4.662	3.88
7½	90	6217	124.	82.9	56.5	28.2	15.54	12.43	10.36	7.77	6.217	5.18
10	90	8288	165.	110.	75.5	37.6	20.72	16.57	13.81	10.36	8.288	6.90
15	90	12433	248.	165.	113.	56.5	31.08	24.86	20.72	15.53	12.43	10.86
20	90	16578	331.	221.	150.	75.3	41.44	33.15	27.63	20.72	16.57	13.98
25	90	20722	414.	276.	188.	94.1	51.8	41.6	34.5	25.9	20.7	17.2
30	90	24866	497	331.	226.	113.	62.	49.7	41.4	31.	24.8	20.7
40	90	33155	663.	442.	301.	150.	82.8	66.3	55.2	41.4	33.1	27.6
50	90	41444	828.	552.	376.	188.	103.	82.8	69.	51.8	41.4	34.5
60	90	49733	994.	663.	452.	226.	124.	99.4	82.8	62.	49.7	41.4
70	90	58022	1160.	773.	527.	263.	145.	116.	96.7	72.5	58.	48.3
80	90	66311	1326.	884.	602.	301.	165.	132.	110.	82.9	66.3	55.2
90	90	74599	1491.	994.	678.	339.	186.	149.	124.	93.	74.5	62.
100	90	82888	1657.	1105.	753.	376.	207.	165.	138.	103.	82.8	69.
120	90	99457	1989.	1326.	904.	452.	248.	198.	165.	124.	99.	82.8
150	90	124312	2486.	1657.	1131.	565.	310.	248.	207.	155.	124.	103.



MULTIPOLAR MOTOR DIRECT-CONNECTED TO 60-INCH FAN.

Sprague Electric Company.

TABLE II.

Volts Lost at Different Per Cent Drop.

Drop per cent.	VOLTAGE.											
	52	75	100	110	220	400	500	600	800	1000	1200	2000
½	.261	.376	.502	.552	1.10	2.01	2.51	3.01	4.02	5.02	6.03	10.05
1	.525	.757	1.01	1.11	2.22	4.04	5.05	6.06	8.08	10.10	12.12	20.2
1½	.2918	1.14	1.52	1.67	3.35	6.09	7.61	9.13	12.1	15.2	18.2	30.4
2	1.06	1.53	2.04	2.24	4.48	8.16	10.2	12.2	16.3	20.4	24.4	40.8
2½	1.33	1.92	2.56	2.82	5.64	10.25	12.8	15.3	20.5	25.6	30.7	51.2
3	1.61	2.31	3.09	3.40	6.80	12.37	15.4	18.5	24.7	30.9	37.1	61.8
4	2.16	3.12	4.16	4.58	9.16	16.66	20.8	24.9	33.3	41.6	49.9	83.3
5	2.73	3.94	5.26	5.78	11.37	21.05	26.3	31.5	42.1	52.6	63.1	105.
6	3.31	4.78	6.38	7.02	14.04	25.53	31.9	38.2	51.	63.8	76.5	127.
7	3.91	5.64	7.52	8.27	16.55	30.10	37.6	45.1	60.2	75.2	90.3	150.
8	4.52	6.52	8.69	9.56	19.13	34.78	43.4	52.1.	69.5	86.9	104.	173.
9	5.14	7.41	9.89	10.87	21.75	39.56	49.4	59.3	79.1	98.9	118.	197.
10	5.77	8.33	11.11	12.22	24.44	44.44	55.5	66.6	88.8	111.	133.	222.
11	6.42	9.26	12.35	13.59	27.19	49.43	61.7	74.1	98.8	123.	148.	247.
12	7.09	10.22	13.63	14.99	29.99	54.54	68.1	81.8	109.	136.	163.	272.
13	7.76	11.10	14.94	16.43	32.87	59.76	74.7	89.6	119.	149.	179.	298.
14	8.46	12.20	16.27	17.90	35.81	65.1	81.3	97.6	130.	162.	195.	325.
15	9.17	13.23	17.64	19.41	38.82	70.5	88.2	105.	141.	176.	211.	352.
20	13.	18.75	25.	27.50	55.	100.	125.	150.	200.	250.	300.	400.
25	17.33	25.	33.33	36.66	73.33	133.	166.	200.	266.	333.	400.	666.

OUTSIDE WIRING AND CONSTRUCTION.

Service Wires (those leading from the outside main wire to the buildings and attached to same) should be "Rubber-Covered."

Line Wires, other than service wires, should have an approved "weatherproof covering."

Bare Wires may be used through uninhabited and isolated territories free from all other wires, as in such places wire cover-

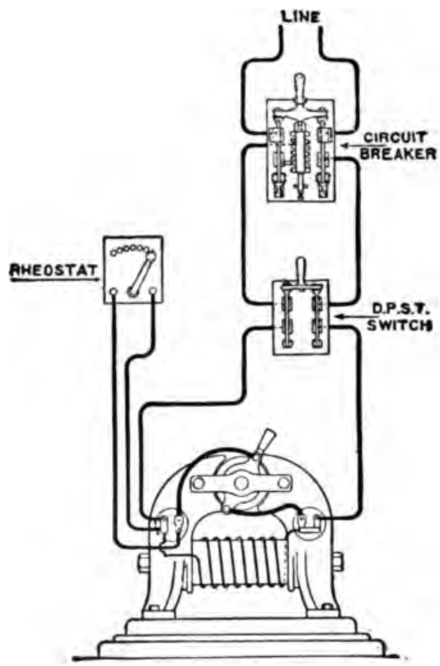


Fig. 2.

An approved installation in every detail; wiring connections for shunt-wound bipolar motor, using circuit breaker instead of double-pole fuse cut-out.

ing would be of little use, as it is not relied on for pole insulation, and is not needed for other purposes, because the permanent insulation of the wires from the ground is assured by the glass or porcelain petticoat insulators to which the wires are secured.

Tie Wires should have an insulation equal to that of the conductors they confine.

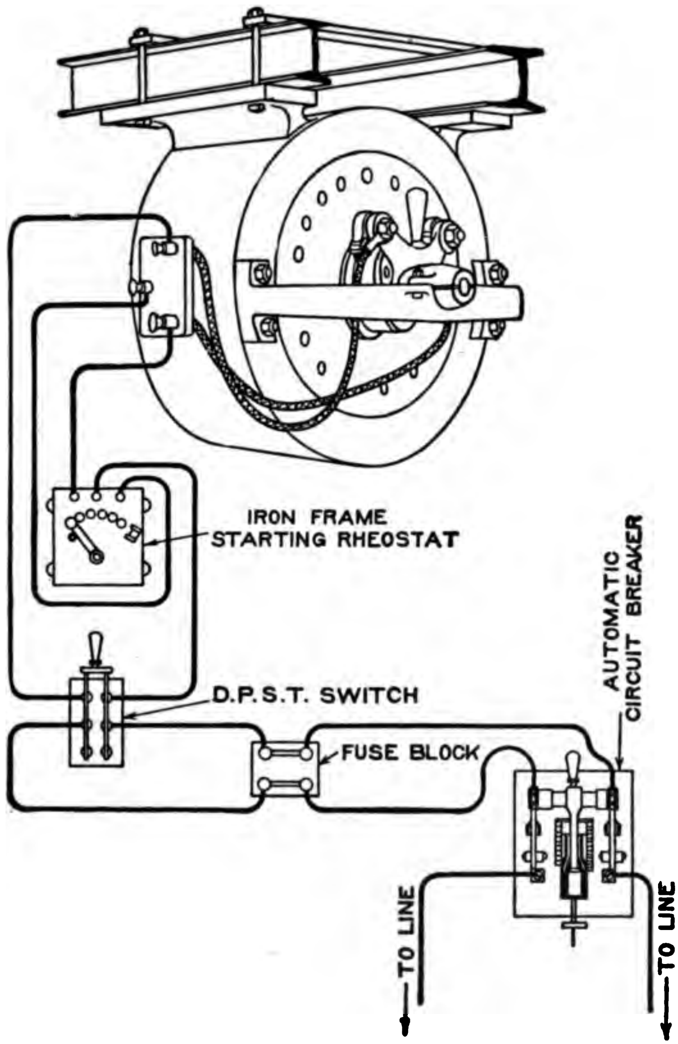
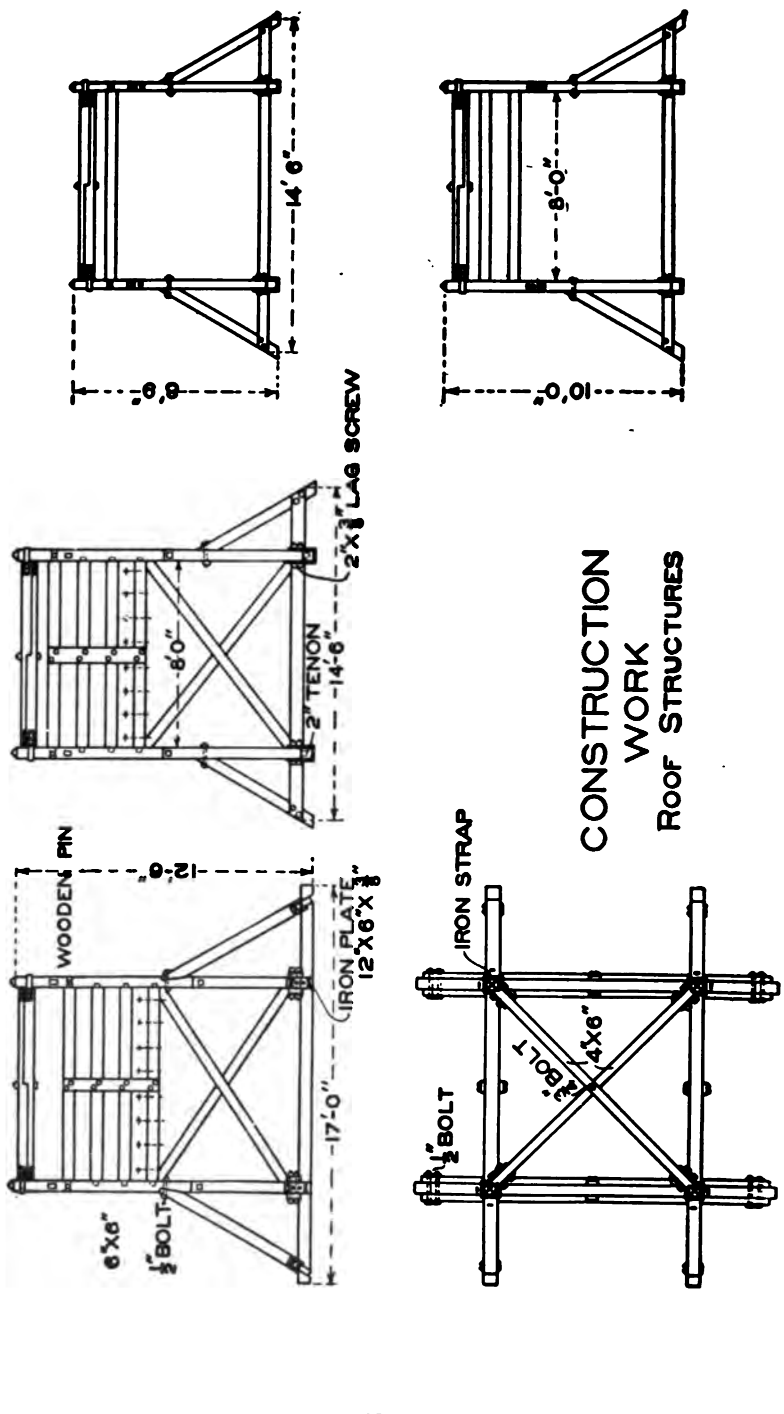


Fig. 3.

An approved installation in every detail, with wiring connections for shunt-wound multipolar slow speed ceiling motor for direct connection to line shaft. Using both circuit breaker and double-pole fuse cut-out.



CONSTRUCTION
WORK
ROOF STRUCTURES
14' 6"
6' 9"
8'-0"
10'-0"
LAG SCREW
2" TENON
14'-6"
WOODEN PIN
12'-6"
IRON PLATE
17'-0"
6"X6"
BOLT
IRON STRAP
4"X6"
BOLT

Fig. 4.

Space Between Wires for outside work, whether for high or low tension, should be at least one foot, and care should be exercised to prevent any possibility of a cross connection by water. Wires should never come in contact with anything except their insulators.

Roof Structures. If it should become necessary to run wires over a building, the wires should be supported on racks which will raise them seven feet above flat roofs or at least one foot above the ridge of pitched roofs. See Fig. 4.

Guard Arms. Whenever sharp corners are turned, each cross arm should be provided with a dead insulated guard arm to prevent the wires from dropping down and creating trouble, should their insulating support give way.

Petticoat Insulators should be used exclusively for all outside work, and especially on cross arms, racks, roof structures and service blocks. Porcelain knobs, cleats or rubber hooks should never be used for this heavy outside work.

Splicing of two pieces of wire or cable should be done in such manner as to be mechanically and electrically secure without solder. The joints should then be soldered to prevent corrosion and consequent bad contact. All joints thus made should be covered with an insulation equal to that of the conductors.

Tree Wiring. Whenever a line passes through the branches of trees, it should be properly supported by insulators, as shown in Fig. 5, to prevent the chafing of the wire insulation and grounding the circuit.

Service Blocks which are attached to buildings should have at least two coats of waterproof paint to prevent the absorption of moisture.

Entrance Wires. Where the service wires enter a building they should have drip loops outside, and the holes through which the conductors pass should be bushed with non-combustible, non-absorptive insulating tubes slanting upward toward the inside. See Fig. 6.

Telegraph and Telephone wires should never be placed on the same cross-arm with light or power wires, especially when alternating currents are used, as trouble will arise from induc-

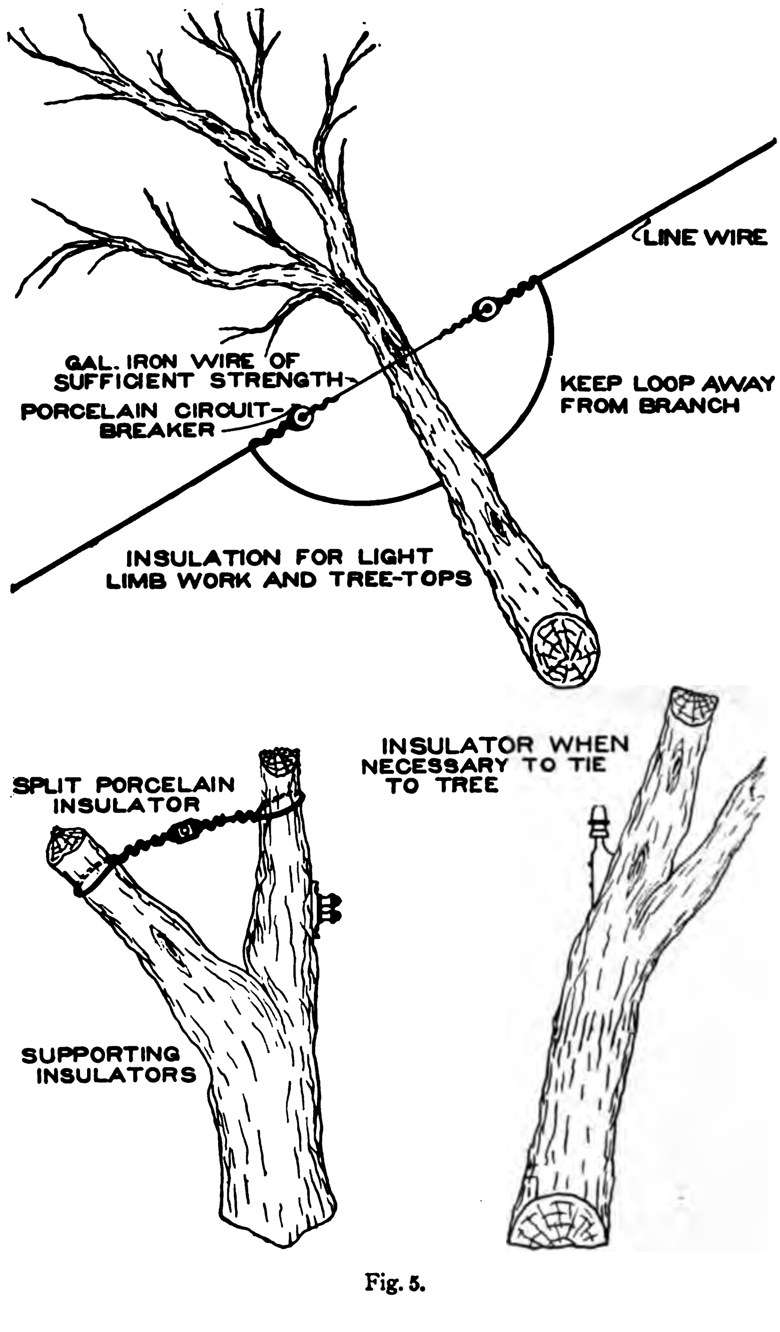

LINE WIRE
GAL. IRON WIRE OF SUFFICIENT STRENGTH
PORCELAIN CIRCUIT-BREAKER
KEEP LOOP AWAY FROM BRANCH
INSULATION FOR LIGHT LIMB WORK AND TREE-TOPS
SPLIT PORCELAIN INSULATOR
INSULATOR WHEN NECESSARY TO TIE TO TREE
SUPPORTING INSULATORS

Fig. 5.

tion, unless expensive special construction, such as the transposing of the lighting circuits, be resorted to at regular intervals. Even under these conditions it is bad practice, as an accidental contact with the lighting or power circuit might result in starting a fire in the building to which the telephone line is connected. If, however, it is necessary to place telegraph or telephone wires on the same poles with lighting or power wires, the distance between the two inside pins of each cross-arm should not be less than twenty-six inches, and the metallic sheaths to cables should be thoroughly and permanently connected to earth.

Transformers should not be placed inside of any buildings except central stations, and should not be attached to the outside walls of buildings, unless separated therefrom by substantial supports.

In cases where it is impossible to exclude the transformer and primary wiring from entering the building, the transformer should be located as near as possible to the point where the primary wires enter the building, and should be placed in a vault or room constructed of or lined with fire-resisting material, and containing nothing but the transformer. In every case the transformer must be insulated from the ground and the room kept well ventilated. It is of course the safest and best practice to place all transformers on poles away from the building that is to be lighted, as illustrated in Fig. 7.

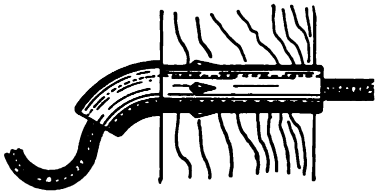


Fig. 6.
Porcelain tube, used where wires enter buildings, showing drip loop in wire.

The Grounding of Low-Potential Circuits is allowed only when such circuits are so arranged that under normal conditions of service there will be no passage of current over the ground wire.

In Direct-Current 3-Wire Systems the neutral wires may be grounded, and when grounded the following rules should be complied with:

1. They should be grounded at the central station on a metal plate buried in coke beneath permanent moisture level, and

also through all available underground water and gas pipe systems.

2. In underground systems the neutral wire should also be grounded at each distributing box through the box.

3. In overhead systems the neutral wire should be grounded every 500 feet.

When grounding the neutral point of transformers or the

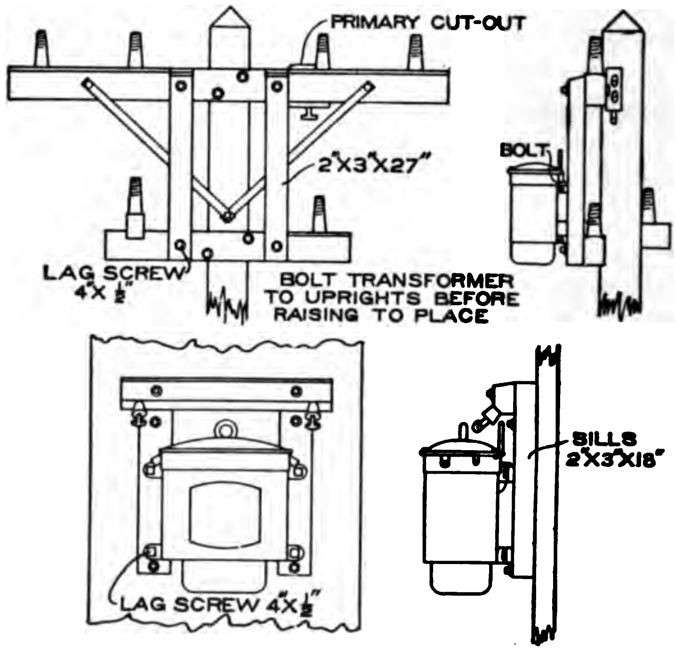


Fig. 7.
Construction work; installing transformers.

neutral wire of distributing systems the following rule should be complied with:

1. Transformers feeding two-wire systems should be grounded at the center of the secondary coils, and when feeding systems with a neutral wire, should have the neutral wire grounded at the transformer, and at least every 500 feet for underground systems.

In making ground connections on low-potential circuits, the ground wire in direct-current 3-wire systems should not at central stations be smaller than the neutral wire, and not smaller than No. 6 B. & S. elsewhere.

In Alternating-Current Systems the ground wire should never be less than No. 6 B. & S., and should always have equal carrying capacity to the secondary lead of the transformer, or the combined leads where transformers are banked.

These wires should be kept outside of buildings, but may be directly attached to the building or pole, and should be carried in as nearly a straight line as possible, all kinks, coils and sharp bends being avoided.

The ground connection for central stations, transformer sub-stations, and banks of transformers should be made through metal plates buried in coke below permanent moisture level, and connection should also be made to all available underground piping systems, including the lead sheath of underground cables.

For individual transformers and building services the ground connection may be made to water or other piping systems running into the buildings. This connection may be made by carrying the ground wire into the cellar and connecting on the street side of meters, main cocks, etc., but connection should never be made to any lead pipes which form part of gas services.

In connecting ground wires to piping systems, wherever possible, the wires should be soldered into one or more brass plugs and the plugs forcibly screwed into a pipe fitting, or, where the pipe is cast iron, into a hole tapped into the pipe itself. For large stations, where connecting to underground pipes with bell and spigot joints, it is well to connect to several lengths, as the pipe joints may be of rather high resistance. Where such plugs cannot be used, the surface of the pipe may be filed or scraped bright, the wire wound around it, and a strong clamp put over the wire and firmly bolted together.

Where ground plates are used, a No. 16 copper plate, about 3 by 6 feet in size, with about two feet of crushed coke or charcoal, about pea size, both under and over it, would make a ground of sufficient capacity for a moderate-sized station, and would probably answer for the ordinary sub-station or bank of transformers. For a large central station considerable more area might be neces-

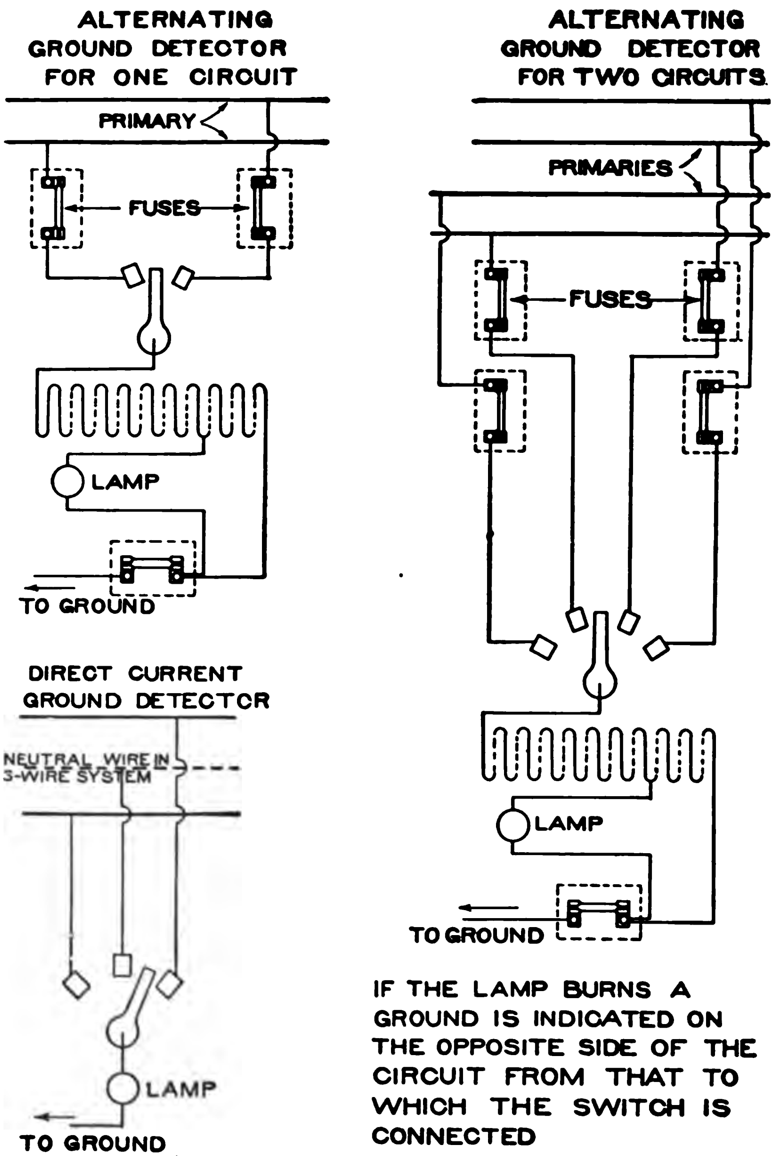


Fig. 8.

Connections of Ground Detectors.

sary, depending upon the underground connections available. The ground wire should be riveted to such a plate in a number of places, and soldered for its whole length. Perhaps even better than a copper plate is a cast iron plate, brass plugs being screwed into the plate to which the wire is soldered. In all cases, the joint between the plate and the ground wire should be thoroughly protected against corrosion, by suitable painting with waterproof paint or some equivalent.

Ground Detectors. Fig. 8 illustrates a few practical methods of detecting grounds on alternating and direct-current circuits which have not been purposely grounded.

In using any one of these methods for detecting grounds, always see that the circuit to ground is left open after testing the outside circuits.

Some central station men are in the habit of leaving the ground circuit closed on one side constantly in order that any ground that might occur on the other side may be instantly noticed. This, however, is bad practice, as it greatly reduces the insulation of the whole system. Test all circuits at least once a day.

It is sometimes necessary to know just what the insulation resistance of a line, or of the wiring in a building, is in ohms. This can be found very readily, and closely enough for all practical purposes, by using a Weston volt meter in the following manner:

Connect with a wire from one side of the circuit to one binding post of the volt meter, and with another piece of wire connect a water pipe to the other binding post of the volt meter. If the needle or pointer shows any deflection we know there is a ground, or leakage, on the opposite side of the circuit to which the volt meter is connected.

The resistance of this ground leak may be found by the following formula:

$R = r\left(\frac{V}{v} - 1\right)$ ohms when R = resistance of ground leak required, r = resistance of volt meter, V = voltage between the positive and negative sides of the line, v = reading in volts, on the instrument, produced by the leakage.

Primary Wiring. Primary wires should be kept at least ten inches apart, and at that distance from conducting material. Primary wires carrying over 3,500 volts should not be brought into or over any building other than the central power station or sub-station.

Wires for Outside Use have in most cases a "weatherproof" insulation, except service wires, which should be "rubber-covered." Any insulating covering for wires exposed to the weather on poles is in a short time rendered useless. The real insulation of the system will be found to be dependent upon the porcelain or glass insulators.

POLES FOR LIGHT AND POWER WIRES.

It is essential to a proper installation that the poles receive due consideration, a fact that is too often overlooked.

In selecting the style of pole necessary for a certain class of work the conditions and circumstances should be considered. Poles may be arranged in three classes, the size of wire which they are to carry respectively being one of the important regulating circumstances.

First Class: Alternating-current plants for lighting small towns. Main line of poles should consist of poles from 30 to 35 feet long, with 6-inch tops. These are strong enough for all the weight that is placed upon them. No pole less than 30 feet with 6-inch top should be placed on a corner for lamps. The height of trees, of course, must be considered in many cases. For the Edison municipal system, where more than one set of wires are used for street lighting, a 6-inch top should be the size of the poles, the length being not less than 30 feet, and greater than this if the streets be hilly and filled with trees.

Second Class: Town lighting by arc lights. All poles should be at least 6-inch tops. The corner poles should be 6½-inch tops; and wherever the cross-arms are placed on a pole at different angles, the pole should be at least a 6½-inch top. A 30-foot pole is sufficiently long for the main line, but it would be advisable to place 35-foot poles on corners.

Third Class: Where heavy wire, such as No. 00, is used for feeder wire, the poles should be at least 7-inch tops. Where mains are run on the same pole line the strain is somewhat lessened, and poles of smaller size will answer all purposes.

Cull Poles. The question as to what is a cull pole is something on which many authorities differ. Of course, if specifications call for a certain sized pole, parties supplying the poles should be compelled to send the sizes called for. All poles that are smaller at the top than the sizes agreed upon, are troubled with dry rot, large knots and bumps, have more than one bend, or have a sweep of over twelve inches, should certainly be classed as cull poles. Specifications for electric light and power work should be, and in many cases are, much more severe than those required by telegraph lines. A cull pole, one of good material, is the best thing for a guy stub, and is frequently used for this purpose. A cedar pole is always preferable to any other, owing to the fact that it is very light compared with other timber, and is strong, durable and very long lived.

Pole Setting. It seems to be the universal opinion of the best construction men that a pole should be set at least five feet in the ground, and six inches additional for every five feet above thirty-five feet. Also additional depths on corners. Wherever there is much moisture in the ground, it is well to paint the butt end of the pole, or smear it with pitch or tar, allowing this to extend about two feet above the level of the ground. This protects the pole from rot at the base. The weakest part of the pole is just where it enters the ground. Never set poles farther than 125 feet apart; 110 feet is good practice.

Pole Holes should be dug large enough so that the butt of the pole can be dropped straight in without any forcing, and when the pole is in position only one shovel should be used to fill in, the earth being thoroughly tamped down with iron tampers at every step until the hole is completely filled with solidly packed earth. Where the ground is too soft for proper tamping, a grouting composed of one part of Portland cement to two parts of sand, mixed with broken stone, may be used to make an artificial foundation.

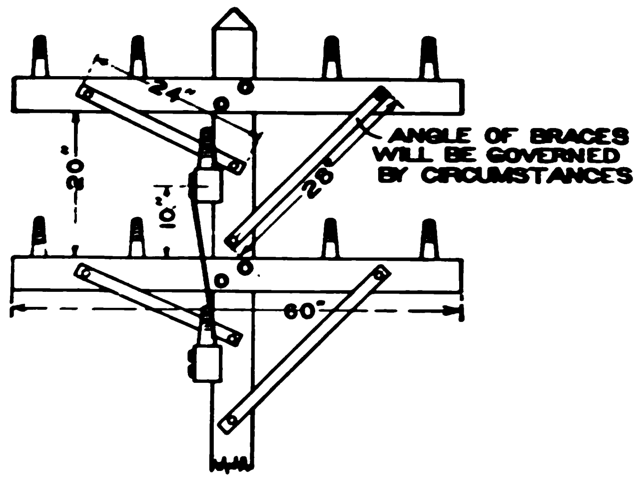


FIG. 1

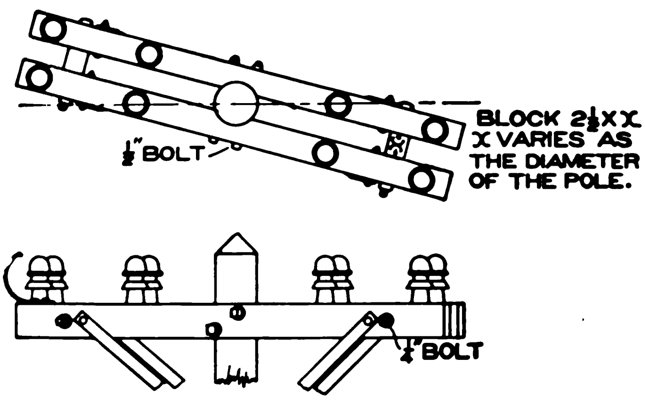


FIG. 2

Fig. 9.

CONSTRUCTION WORK; POSITION OF CROSS-ARMS WHEN TURNING CORNERS.

When running a heavy line wire it is necessary to use two cross-arms fastened as shown above in Fig. 2. If lines are not heavy, only one cross-arm will be necessary. In case lines cross the street diagonally, the arms where the wires leave and those to which they run are both set at an angle. When turning an abrupt corner only one arm is turned. The above cannot be used where feeders tap into double branches. In such a case the method given in Fig. 1 is used.

TABLE III.

Cedar Poles for Electric Light Work.

SIZE.	Average weight, pounds each.	No. of Poles to a Car.	SIZE.	Average weight, pounds each.	No. of Poles to a Car.
25 ft., 5-inch top	200	150	35 ft., 7-inch top	650	90
25 " 5½ " "	225	130	40 " 6 " "	800	80
25 " 6 " "	250	120	40 " 7 " "	900	75
28 " 7 " "	400	80	45 " 6 " "	900	70
30 " 5 " "	300	110	45 " 7 " "	1000	65
30 " 6 " "	350	90	50 " 6 " "	1200	55
30 " 7 " "	420	75	55 " 6 " "	1400	45
35 " 6 " "	550	100			

Painting. When poles are to be painted, a dark olive green color should be chosen, in order that they may be as inconspicuous as possible. One coat of paint should be applied before the pole is set, and one after the pole is set. Tops should be pointed to shed water.

All poles 35 feet long and over must be loaded on two cars.

For chestnut poles add 50 per cent to weights as given in table.

Cross-Arms. The distance from the top of the pole to the cross-arm should be equal to the diameter of pole at the top. All cross-arms should be well painted with one coat of paint before placing, and must be of standard size as shown in the diagrams. Cross-arms of four or more pins should be braced, using one or two braces as occasion demands. Cross-arms on one pole should face those on the next, thereby making the cross-arms on every other pole face in one direction. All pins should have their shanks dipped in paint and should be driven into the cross-arm while the paint is wet. The upper part of the pin should also be painted. Iron pins may be furnished for corners where there is a heavy strain, but are not advised, it being preferable to use the construction as shown in the diagrams. Put double arms on the pole where feeder wires end.

Guard Irons. Guard irons should be placed at all angles in lines, and on break-arms.

Steps. All junction and lamp poles should be stepped so that the distance between steps on the same side of the pole will not be over 36 inches. Poles carrying converters should also be stepped.

TABLE IV.
Pole Line Data.

Gauge Number (B. & S.)		4/0	3/0	2/0	1/0	1	2	3	4	5	6	7	8
Diam. of Bare Wire, in Thousandths		.460	.40964	.3648	.3249	.2893	.2576	.2294	.2043	.1819	.1620	.1442	.1285
Ohms Res. B. Wire per Mile, 75° Fahr.		.25902	.32667	.41188	.5499	.6910	.8719	1.099	1.400	1.754	2.213	2.812	3.539
Wt. (lbs.) per 1000 feet Insulated Wire		826	611	460	357	300	244	204	168	119	100	84	71
Weight per Mile (approximate) of Insulated Wire		4360	3225	2225	1880	1580	1285	1075	885	625	525	440	373
No. of Poles per Lineal Mile.	Distance Between Poles (feet).	Approximate Weight of Insulated Wire Between Poles.											
20	264.00	218.0	161.3	121.3	94.0	79.0	64.25	53.75	44.25	31.2	26.25	22.	18.65
21	251.40	208.0	153.6	115.5	89.53	75.0	61.2	51.2	42.2	30.0	25.0	20.96	17.8
22	240.10	198.2	146.6	110.3	85.5	71.9	58.5	48.9	40.3	28.41	23.9	20.0	16.96
23	229.56	189.69	140.3	105.5	81.74	68.70	55.88	46.8	38.5	27.17	22.83	19.2	16.22
24	220.00	181.7	134.4	101.0	78.34	65.84	53.54	44.8	36.91	26.05	21.9	18.34	15.55
25	211.20	174.4	129.	97.0	75.20	63.2	51.40	53.0	35.4	25.0	21.0	17.6	14.92
26	203.07	167.7	124.04	93.3	72.40	60.8	49.42	41.34	34.04	24.04	20.19	16.93	14.35
27	195.55	161.5	119.5	89.81	69.63	58.52	47.22	40.00	32.77	23.15	19.45	16.30	13.82
28	188.55	155.7	115.2	86.61	67.50	56.43	45.90	38.39	31.61	22.33	18.76	15.72	13.33
29	182.09	150.34	111.3	83.62	64.82	54.48	44.31	37.07	30.52	21.56	18.11	15.18	12.87
30	176.00	145.34	107.5	80.85	62.67	52.67	42.84	35.84	29.50	20.86	17.50	14.67	12.44
31	170.30	140.65	104.04	78.23	60.65	50.97	41.46	34.68	28.55	20.17	16.94	14.20	12.04
32	165.00	136.25	100.80	75.80	58.75	49.38	40.16	33.60	27.66	19.54	16.41	13.75	11.72
33	160.00	132.13	97.73	73.49	56.97	47.88	38.94	32.58	26.82	18.94	15.91	13.34	11.31
34	155.29	128.24	94.86	71.83	55.30	46.48	37.80	31.62	26.03	18.39	15.45	12.95	10.98
35	150.85	124.58	92.15	69.29	53.72	45.15	36.73	30.72	25.29	17.86	15.00	12.58	10.66
36	146.66	121.12	89.59	67.37	52.23	43.89	35.70	29.87	24.59	17.37	14.59	12.23	10.37
37	142.70	117.84	87.17	65.55	50.82	42.71	34.73	29.06	23.92	16.90	14.19	11.90	10.09
38	138.96	114.74	84.87	63.82	49.48	41.58	33.82	28.29	23.29	16.45	13.82	11.58	9.82
39	135.38	111.80	82.69	62.20	48.21	40.52	32.95	27.57	22.69	16.03	13.47	[illegible]	9.57
40	132.00	109.00	80.63	60.63	47.00	39.50	32.13	26.88	22.13	15.63	13.13	[illegible]	9.33
41	128.78	106.35	78.66	59.15	45.86	38.58	31.35	26.22	21.60	[illegible]	[illegible]	[illegible]	9.10
42	125.71	103.81	76.79	57.74	44.77	37.62	30.60	25.60	[illegible]	[illegible]	[illegible]	10.48	8.89
43	122.79	101.40	75.00	56.40	43.73	36.75	29.90	25.00	[illegible]	[illegible]	[illegible]	10.24	8.68
44	120.00	99.10	73.30	55.12	42.73	35.91	29.21	24.44	[illegible]	[illegible]	[illegible]	10.00	8.48
45	117.33	96.89	71.67	53.90	41.80	35.12	28.56	23.90	19.67	13.90	[illegible]	9.78	8.30
46	114.78	94.79	70.11	52.72	40.88	34.35	27.94	23.37	19.24	13.59	11.42	9.57	8.11
47	112.34	92.77	68.62	51.60	40.00	33.62	27.35	22.90	18.83	13.30	11.18	9.37	7.94
48	110.00	90.84	67.20	50.52	39.17	32.92	26.78	22.40	18.44	13.03	10.94	9.17	7.78
49	107.75	88.99	65.82	49.49	38.36	32.25	26.03	21.94	18.07	12.77	10.72	8.98	7.62
50	105.60	87.20	64.50	48.50	37.60	31.60	25.70	21.50	17.70	12.50	10.50	8.80	7.46
51	103.52	85.50	63.24	47.55	36.97	31.00	25.20	21.09	17.36	12.26	10.30	8.63	7.32
52	101.53	83.85	62.02	46.64	36.16	30.39	24.75	20.68	17.02	12.02	10.10	8.47	7.18
53	99.64	82.27	60.86	45.76	35.48	29.82	24.25	20.29	16.70	11.80	9.92	8.31	7.04
54	97.77	80.75	59.73	44.91	34.82	29.26	23.80	19.91	16.40	11.58	9.73	8.15	6.91
55	96.00	79.28	58.64	44.10	34.19	28.73	23.37	19.55	16.10	11.37	9.55	8.00	6.78

COPPER WIRE BRAZING FURNACE.
Rockwell Engineering Co.

Guys. All poles at angles in the line must be properly guyed, using No. 4 B. & S. galvanized iron wire, or two No. 8 wires twisted. All junction poles should also be guyed. Never attach a guy wire to a pole so that it prevents a cross-arm from being removed.

For alternating work, double petticoat insulators are recommended. Pole brackets, except in connection with the tree insulators, should not be used.

Tape should be secured at either end of a joint by a few turns of twine. When looping for lamps, etc., leave coiled sufficient wire, without waste, to reach lamp or building without joints. In cutting arc or incandescent lamps into an existing circuit, use a piece of "rubber-covered" wire. Feeder wires should be strung on the cross-arms above the mains.

For good distribution, arc lamps should not be placed more than 800 feet apart. The lamps may be brought nearer together if a greater degree of illumination is desired.

Primary Wires on Poles. When running more than one circuit of primaries upon the same line of poles the wires of each circuit should be run parallel and on adjacent pins, as shown below, so as to avoid any fluctuation in the lamps due to induction. The lines lettered A and A are for circuit No. 1, and B and B for circuit No. 2, etc.

.............................A
.............................A
.............................B
.............................B

When connecting transformers to 1,000-volt mains a double-pole cut-out is placed in the primary circuit. For 2,000-volt circuits a single-pole cut-out should be placed in each side of the line, thus avoiding any possible short circuit due to an arc being established across the contacts of the double-pole cut-out. This, owing to the greater difference of potential between opposite poles, is liable to occur when the fuses "blow."

INSIDE WIRING.

Approved "Rubber-Covered" Wire should be used exclusively in all interior wiring. Although the Fire Underwriters

allow "Slow Burning" weatherproof wire to be used in dry places when wiring is entirely exposed to view and rigidly supported on porcelain or glass insulators, "Rubber-Covered" wire is always preferable.

The copper conductors, before being rubber covered, should be thoroughly tinned, and the thickness of the rubber covering should conform to the following table:

TABLE V.

Requisite Thickness of Rubber Covering for Wires.

For voltages up to 600:

From No.	18	to No.	16	inclusive,	$\frac{1}{32}$ in.
"	14	to "	8	"	$\frac{3}{64}$ in.
"	7	to "	2	"	$\frac{1}{16}$ in.
"	1	to "	0000	"	$\frac{5}{64}$ in.
"	0000	to "	500000 c. m.	"	$\frac{3}{32}$ in.
"	500000 c. m.	to "	1000000 "	"	$\frac{7}{64}$ in.
Larger than		"	1000000 "	"	$\frac{1}{8}$ in.

For voltages between 600 and 3,500:

From No. 14 to No.	1	inclusive,	$\frac{3}{32}$ in.	
" 0 to "	500000 c. m.	"	$\frac{3}{32}$ in.	covered by
Larger than	500000 "	"	$\frac{4}{32}$ in.	braid or tape.

"Slow Burning Weatherproof" Wire should have an insulation consisting of two coatings, the inner one to be fireproof in character and the other to be weatherproof. The inner fireproof coating should comprise at least six-tenths of the total thickness of the wall.

The complete covering should be of a thickness not less than that given in the following table:

TABLE VI.

Requisite Thickness of Slow Burning Weatherproof Insulation.

From No.	14	to No.	8	inclusive,	$\frac{3}{64}$ in.
"	7	to "	2	"	$\frac{1}{16}$ in.
"	2	to "	0000	"	$\frac{5}{64}$ in.
"	0000	to "	500000 c. m.	"	$\frac{3}{32}$ in.
"	500000 c. m.	to "	1000000 "	"	$\frac{7}{64}$ in.
Larger than		"	1000000 "	"	$\frac{1}{8}$ in.

"Weatherproof" Wire, for out-door use, should consist of at least three braids thoroughly impregnated with a dense moisture-repellant which should stand a temperature of 180° Fahrenheit without dripping. The thickness should correspond to that of "Slow Burning Weatherproof" and the outer surface should be thoroughly slicked down.

Carrying Capacity of Wires. Table VII gives the safe carrying capacity of wires from No. 18 B. & S. to cables of 2,000,000 circular mils.

No wires smaller than No. 14 should be used except for fixture wiring and pendants, in which cases as small as No. 18 may be used.

TABLE VII.

Safe Carrying Capacity of Wires.

Gauge No. B. & S. Diameter Mils. Area Circular Mils. No. Amperes Open Work. No. Amperes Concealed Work. Ohms Per 1000 Ft. Lbs. per 1000 Ft. Bare. Lbs. Per 1000 Ft. Insulated. No. and Size of Wires for Cables.

Gauge No. B. & S.	Diameter, Mils.	Area, Circular Mils.	No. Amperes, Open Work.	No. Amperes, Concealed Work.	Ohms per 1000 Ft.	Lbs. per 1000 Ft. Bare.	Lbs. per 1000 Ft. Insulated.	No. and Size of Wires for Cables.
18...	40	1,624	5	3	6.3880	4.92	18	
17...	45	2 048	6	4	5.0660	6.20	21	
16...	51	2,583	8	6	4.0176	7.82	25	
15...	57	3,257	10	8	3.1860	9.86	31	
14...	64	4,106	16	12	2.5266	12.44	38	
13...	72	5,178	19	14	2.0037	15.68	43	
12...	81	6,530	23	17	1.5890	19.77	48	
11...	91	8,234	27	21	1.2602	24.93	64	
10...	102	10,380	32	25	.99948	31.44	80	
9...	114	13,090	39	29	.79242	39.65	97	
8...	128	16,510	46	33	.62849	49.99	116	
7...	144	20,820	56	39	.49845	63.03	118	
6...	162	26,250	65	45	.39528	79.49	166	
5...	182	33,100	77	53	.31346	100.23	196	
4...	204	41,740	92	63	.24858	126.40	228	
3...	229	52,630	110	75	.19714	159.38	265	
2...	258	66,370	131	88	.15633	200.98	296	
1...	289	83,690	156	105	.12398	253.43	329	
0...	325	105,500	185	125	.09827	319.74	421	
00...	365	133,100	220	150	.07797	402.97	528	
000...	410	167,800	262	181	.06134	508.12	643	
0000...	460	211,600	312	218	.04904	640.73	815	
Cables.	630	300,000	405	273	.03355	932.	Weight of insulations on cables varies for different kinds of work.	37-090
" .	727.3	400,000	503	332	.02516	1242.		37-1039
" .	814.5	500,000	595	390	.02013	1553.		61-0905
" .	891.9	600,000	682	440	.01666	1863.		61-0991
" .	963.9	700,000	765	488	.01438	2174.		61-1071
" .	1030.5	800,000	846	540	.01258	2474.		61-1145
" .	1092.6	900,000	924	585	.01118	2795.		61-1214
" .	1152.	1,000,000	1000	630	.01006	3106.		61-128
" .	1208.7	1 100,000	1075	675	.00915	3416.		61-1343
" .	1262.8	1,200,000	1147	715	.00838	3727.		91-1148
" .	1314.5	1,300,000	1217	755	.00769	4038.		91-1195
" .	1364.	1,400,000	1287	795	.00715	4348.		91-124
" .	1413.5	1,500,000	1356	835	.00667	4658.		91-1285
" .	1458.6	1,600,000	1423	875	.00625	4968.		91-1326
" .	1503.7	1 700,000	1489	910	.00588	5278.		91-1367
" .	1547.7	1,800 000	1554	945	.00556	5588.		127-1195
" .	1571.9	1,900,000	1618	980	.00527	5898.		127-1223
" .	1630.2	2,000,000	1681	1015	.00500	6208.		127-1254

Tie Wires should have an insulation equal to that of the conductors they confine.

Splicing should be done in such manner as to make the wires mechanically and electrically secure without solder; then they should be soldered to insure preservation from corrosion and from consequent heating due to poor contact.

Stranded Wires should have their tips soldered before being fastened under clamps or binding screws. When the stranded wires have a conductivity greater than No. 10 B. & S. copper wire, they should be soldered into lugs. All joints should be soldered in preference to using any kind of splicing device.

Wiring Table. The following examples show the method of using the table on page 40:

1. What size of wire should we use to run 50 16-candle-power lamps of 110 volts, a distance of 150 feet to the center of distribution with the loss of 2 volts?

First multiply the amperes, which will be 25.5 (50 16-c. p. 110-v. lamps take 25.5 amperes, see table on page 57), by the distance, 150 feet, which will equal 3,825 ampere feet. Then refer to the columns headed "Actual Volts Lost"; and as we are to have a loss of two volts only, look down the column headed 2 until you come to the nearest corresponding number to 3,825, and we find that 3,900 is the best number to use. Put your pencil on the number 3,900 and follow that horizontal column to the left until you come to the vertical column headed "Size B. & S.," and you find that a No. 4 B. & S. wire will be the proper size to use in this case.

2. What size of wire should we use to carry current for a motor that requires 30 amperes and 220 volts, and is situated 200 feet from the distributing pole, the "drop" in volts not to exceed 2 per cent?

First multiply 30 amperes by 200 feet, as we did in the first example, and we get 6,000 ampere feet. Now look at the upper left-hand corner of the table and you will see a vertical column headed "Volts." Go down this column until you come to 220, and follow the horizontal column to the right until you come to the figure 1.8, which is the nearest we can come to a 2 per cent loss without a greater loss or "drop." Place your pencil on the figure 1.8 and follow down the vertical column of figures until you come to the nearest corresponding figure to 6,000, which we find to be 6,200. Then with your pencil on this figure follow the horizontal column to the left, and we find that a No. 5 B. & S. wire is a proper size to use for the above conditions.

3. Supposing we have occasion to inspect a piece of wiring, and find a dynamo operating 50 16-c. p. 110-volt lamps at a distance of 150 feet, and our wire gauge shows that wire in use is a No. 12 B. & S., at what loss, or "drop," are these lamps being operated?

First multiply the amperes, which will be 25.5 (50 16-c. p. 110-v. lamps take 25.5 amperes, see table on page 57), by the distance, 150 feet, and we get 3,825 ampere feet. As we find in use a No. 12 B. & S. wire, we look for the vertical column headed "Size B. & S." and follow it down until we come to 12. With our pencil on the figure 12 we travel along the horizontal line to the right until we come to the nearest corresponding number to 3,825, which we find to be 4,575. Then starting at this number we travel up the vertical column and we find a loss of about 15 actual volts, or, practically, a 12 per cent loss, which would greatly reduce the candle-power or brilliancy of the lamps.

Installation of Wires. All wiring should be kept free from contact with gas, water or other metallic piping, or with any other conductors or conducting material which it may cross, by some continuous and firmly fixed non-conductor, creating a separation of at least one inch. In wet places it should be arranged so that an air space will be left between conductors and pipes in crossing, and the former must be run in such a way that they cannot come in contact with the pipe accidentally.

Wires should be run over rather than under pipes upon which moisture is likely to gather, or which by leaking might cause trouble on a circuit. No smaller size than No. 14 B. & S. gauge should ever be used for any lighting or power work, not that it may not be electrically large enough, but on account of its mechanical weakness and liability to be stretched or broken in the ordinary course of usage. Smaller wire may be used for fixture work, if provided with approved rubber insulation.

Wires should never be laid in or come in contact with plaster, cement, or any finish, and should never be fastened by staples, even temporarily, but always supported on porcelain cleats which will separate the wires at least one-half inch from the surface wired over and keep the wires not less than two and one-half

TABLE VIII.

Wiring for Light and Power Circuits.

To find size of wire, multiply current in amperes by single distance and refer to the nearest corresponding number under column of Actual Volts Lost.

Volts.	Percentage of Loss.																
2000	1.7	1.5	1.4	1.2	1.1	1.0	0.75	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05
1000	3.4	2.9	2.7	2.4	2.2	2.0	1.5	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
500	6.5	5.7	5.2	4.8	4.3	3.9	2.9	2.0	1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4	0.2
220	13.7	12.0	11.0	10.3	9.3	8.3	6.5	4.4	3.9	3.5	3.1	2.7	2.2	1.8	1.4	0.9	0.45
110	—	—	20.0	18.5	17.0	15.4	12.0	8.4	7.6	6.8	6.0	5.2	4.4	3.5	2.7	1.8	0.9
52	—	—	—	—	—	—	22.4	16.1	14.7	13.3	11.8	10.3	8.8	7.1	5.5	3.7	1.9

Actual Volts Lost.

*Carrying Capacity, Amperes	Size B. & S.	35	30	27.5	25	22.5	20	15	10	9	8	7	6	5	4	3	2	1
300	0000	345800	296400	271700	247000	222300	197600	148200	98800	88920	79040	69160	59280	49400	39520	29640	19760	9880
245	000	274400	235200	215600	196000	176400	156800	117600	78400	70560	62720	54880	47040	39200	31360	23520	15680	7840
215	00	217525	186450	170912	155375	139837	124300	93225	62150	55935	49720	43505	37290	31075	24860	18645	12430	6215
190	0	172550	147900	135575	123250	110925	98600	73950	49300	44370	39440	34510	29580	24650	19720	14790	9860	4930
160	1	136850	117300	107525	97750	87975	78200	58650	39100	35190	31280	27370	23460	19550	15640	11730	7820	3910
135	2	108500	93000	85250	77500	69750	62000	46500	31000	27900	24800	21700	18600	15500	12400	9300	6200	3100
115	3	86100	73800	67650	61500	55350	49200	36900	24600	22140	19680	17220	14760	12300	9840	7380	4920	2460
100	4	68250	58500	53625	48750	43875	39000	29250	19500	17550	15600	13650	11700	9750	7800	5850	3900	1950
90	5	54250	46500	42625	38750	34875	31000	23250	15500	13950	12400	10850	9300	7750	6200	4650	3100	1550
80	6	43050	36900	33825	30750	27675	24600	18450	12300	11070	9840	8610	7380	6150	4920	3690	2460	1230
60	8	26985	23130	21202	19275	17347	15420	11565	7710	6939	6168	5397	4626	3855	3084	2313	1542	771
40	10	16975	14550	13337	12125	10912	9700	7275	4850	4365	3880	3395	2910	2425	1940	1455	970	485
30	12	10675	9150	8388	7625	6862	6100	4575	3050	2745	2440	2135	1830	1525	1220	915	610	305
22	14	6720	5760	5280	4800	4320	3840	2880	1920	1728	1536	1344	1152	960	768	576	384	192
15	16	4235	3630	3328	3025	2723	2420	1815	1210	1089	968	847	726	605	484	363	242	121

*Note. In case a larger loss than any given in the table is required, proceed as follows: Divide the ampere feet by 10, and then refer to column Actual Volts Lost divided by 10, from which we find the size wire as before.

inches apart. Three-wire cleats may be used when the neutral wire is run in the center and at least two and one-half inches separate the two outside or + and — wires. This style of wiring is intended for low-voltage systems (300 volts or less); and when it is all open work, rubber-covered wire is not necessary, as "weatherproof" wire may be used. Weatherproof wire should not be used in moulding. Wires should not be fished between floors, walls or partitions, or in concealed places, for any great distance, and only in places where the inspector can satisfy himself that the rules have been complied with, as this style of work is always more or less uncertain.

Twin wires should never be used, except in conduits or when flexible conductors are necessary; they are always unsafe for light or power circuits on account of the short distance between them.

All wiring should be protected on side walls from mechanical injury. This may be done by putting a substantial boxing about the wires, allowing an air space of one inch around the conductors, closed at the top (the wire passing through bushed holes) and extending about five feet above the floor. Sections of iron-armored conduit may be used, and in most cases are preferable, as they take up but little room and are very rigid.

If, however, iron pipes are used with alternating currents, the two or more wires of a circuit should always be placed in the same conduit. If plain iron pipe be used the insulation of that portion of each wire within the pipe should be reinforced by a tough conduit tubing projecting beyond the iron tubing at both ends about two inches.

When crossing floor timbers in cellars or in rooms where they might be exposed to injury, wires should be attached, by their insulating supports, to the under side of wooden strips not less than one-half inch in thickness and not less than three inches wide.

GENERAL FORMULÆ FOR LIGHT AND POWER WIRING.

c. m.=circular mils.

d = length of wire, in feet, on one side of circuit.

n = number of lamps in multiple.

TABLE IX.

Dimensions and Resistances of Copper Wire.

Gauge. No.	Diam. Mils.	Area, Circ. Mils. B. and S. Gauge.	Bare Wire. Lbs. per 1000 ft.	Bare Wire. Lbs. per. Mile.	Bare Wire. Ft. per Pound.	Weatherproof Wire. Lbs. per 1000 ft.	Weatherproof Wire. Lbs. per Mile.	Weatherproof Wire. Ft. per Pound.	*Safe Carrying Capacity, Cur. in Amp.	Ohms per 1000 ft.	Ohms per Mile.	Feet per Ohm.	Area C. M. B. W. G.
0000	460.	211600.	640.73	3383.04	1.56	800	4224.	1.25	312	.04904	.25891	20392.9	206100
000	410.	167800.	508.12	2682.85	1.97	666	3516.	1.50	262	.06184	.32649	16172.1	180600
00	365.	133100.	402.97	2127.66	2.48	500	2640.	2.00	220	.07797	.41168	12825.4	144400
0	325.	105600.	319.74	1688.20	3.13	363	1917.	2.75	185	.09827	.51885	10176.4	115600
1	289.	83690.	253.43	1338.10	3.95	313	1653.	3.20	156	.12398	.65460	8066.0	90000
2	258.	66370.	200.98	1061.17	4.98	250	1320.	4.00	131	.15633	.82543	6396.7	80660
3	229.	52630.	159.38	841.50	6.28	200	1056.	5.00	110	.19714	1.04090	5072.5	67080
4	204.	41740.	126.40	667.38	7.91	144	760.	6.9	92	.24858	1.31248	4022.9	56640
5	182.	33100.	100.23	529.23	9.98	125	660.	8.0	77	.31346	1.65507	3190.2	48400
6	162.	26250.	79.49	419.69	12.58	105	554.	9.5	65	.39528	2.08706	2529.9	41210
7	144.	20820.	63.03	332.82	15.86	87	364.	11.5		.49845	2.63184	2006.2	32400
8	128.	16510.	49.99	263.96	20.00	69	301.	14.5	46	.62849	3.31843	1591.1	27230
9	114.	13090.	39.65	209.35	25.22					.79242	4.18400	1262.0	21900
10	102.	10380.	31.44	165.98	31.81	50	264.	20.0	32	.99948	5.27726	1000.5	17960
11	91.	8234.	24.9	131.65	40.11					1.2602	5.65357	793.56	14400
12	81.	6530.	19.77	104.40	50.58	31	164.	32.0	23	1.5890	8.39001	629.32	11810
13	72.	5178.	15.68	82.792	63.78					2.0037	10.5798	499.06	9025
14	64.	4106.	12.44	65.658	80.42	22	116.	45.0	16	2.5266	13.3405	395.79	6889
15	57.	3257.	9.86	52.069	101.40					3.1860	16.8223	313.87	5184
16	51.	2583.	7.82	41.292	127.87	14	74.	70.0	8	4.0176	21.2130	248.90	4225
17	45.	2048.	6.20	32.746	161.24					5.0660	26.7485	197.39	3364
18	40.	1624.	4.92	25.970	203.31	11	58.	90.0	5	6.3880	33.7285	156.54	2400
19	36.	1288.	3.90	20.594	256.39					8.0555	42.5329	124.14	1764
20	32.	1021.	3.09	16.331	323.32					10.1584	53.6362	98.44	1230

*Safe carrying capacity of exposed wire. Carrying capacity of wire enclosed in moulding is about 40 per cent less. See table on page 37 fifth column.

Approximate weight of weatherproof line wire is 10% less than the weight of underwriters' wire as given above.

c = current in amperes per lamp.

v = volts lost in lines.

r = resistance per foot of wire to be used.

10.8 ohms resistance of one foot of commercial copper wire having a diameter of one mil and a temperature of 75° Fahrenheit.

It is an easy matter to find any of the above values by the following formulæ:

$$c.m. = \frac{10.8 \times 2d \times n \times c}{v}$$

$$v = \frac{10.8 \times 2d \times n \times c}{c.m.} \qquad c = \frac{c.m. \times v}{10.8 \times 2d \times n}$$

$$n = \frac{c.m \times v}{10.8 \times 2d \times c} \qquad 2d = \frac{c.m. \times v}{10.8 \times c \times n}$$

$$r = \frac{v}{n \times c \times 2d}$$

$$v = n \times c \times 2d \times r \qquad c = \frac{v}{2d \times n \times r}$$

$$n = \frac{v}{c \times 2d \times r} \qquad 2d = \frac{v}{n \times c \times r}$$

Arc Light Wiring. All wiring in buildings for constant-current series arc lighting should be with approved rubber-covered wire, and the circuit arranged to enter and leave the building through an approved double-contact service switch, which means a switch mounted on a non-combustible, non-absorptive insulating base and capable of closing the main circuit and disconnecting the branch wires when turned "off." This switch must be so constructed that it will be automatic in action, not stopping between points when started, must prevent an arc between points under all circumstances, and must indicate, upon inspection, whether the current is "on" or "off." Such a switch is necessary to cut the high voltage completely out of the building by firemen in case of fire or when it becomes necessary to make any changes in the lamps or wiring.

This class of wiring should never be concealed or encased except when requested by the Electrical Inspector, and should always be rigidly supported on porcelain or glass insulators which will separate the wiring at least one inch from the surface wired over, and which must be kept at least four inches from each other on all voltages up to 750, and eight inches apart when the voltages exceed 750. No wires carrying a voltage of over 3,500 should be carried into or over any buildings except central stations and sub-stations. All arc light wiring should be protected on side walls and when crossing floor timbers where wires are liable to injury. In mill-construction buildings, arc wires of No. 8 and larger, where not liable to be disturbed, may be separated six inches for voltages up to 750, and ten inches for voltages above 750; may run from timber to timber, not breaking round; and may be supported at each timber only. In running along beams or walls and ceilings they should be supported at intervals not exceeding four and one-half feet.

SPECIAL WIRING.

Special wiring for damp places such as breweries, packing houses, stables, dye houses, paper or pulp mills, or buildings especially liable to moisture or acid or other fumes likely to injure the wires or their insulation, should be done with approved rubber covered wire, and rigidly supported on porcelain or glass insulators which separate the wires at least one inch from the surface wired over, and which must be kept apart at least two and one-half inches. The wire in such damp places should contain no splices as it is almost impossible to tape a splice that will prevent acid fumes from getting at the copper surface.

Moulding Work should always be done with approved rubber covered wire to prevent leakage should the moulding become damp.

This class of work should never be done in concealed or damp places, for fear that water may soak into the wood and cause leakage of current between the wires, burning the wood and starting a fire. The action of the current in a case like this is to convert the wood very gradually into charcoal, then dry the water out and ignite the charcoal thus formed. Great care should be ob served in driving nails into moulding, to avoid puncturing the insulation and possibly grounding the circuit in a way that not only might be difficult to locate, but might cause a concealed fire back of the plastering or wood work to which the moulding is attached.

Moulding should be of hard wood and made of two pieces, a backing and capping, so constructed as to thoroughly encase the wire. It should provide a one-half inch tongue between the conductors and a solid backing, which under the grooves should be not less than three-eighths of an inch in thickness and able to give suitable protection from abrasion.

Concealed Wiring or that which is to be run between walls and floors and their joists, should always be done with approved rubber-covered wire, and should be rigidly supported on porcelain or glass insulators which will separate the wires at least

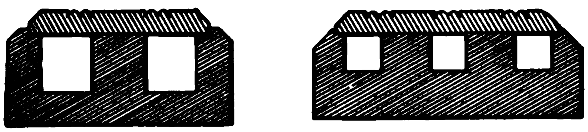


Fig. 10.

Samples of approved moulding when filled and covered with at least two coats of waterproof paint.

one inch from the surface wired over. The wires should be kept at least ten inches apart, and where it is possible should be run singly on separate timbers or joists. The insulators should be placed not farther than four feet apart in any case, and where there is any liability of the wires coming in contact with anything else, due to a possible sagging, the supports should be placed much closer together. In some cases where it is impossible to rigidly support the wiring on porcelain or glass insulators in concealed places, the wires, if not exposed to moisture, may be fished on the loop system if encased throughout in approved continuous flexible tubing or conduit. Fishing under floors or between walls is done by boring holes at suitable distances apart and pushing a flat spring wire from one hole toward the other and catching it with a wire hook. The flexible conduit and wires may then be pulled into place.

Although this fished work may be passed when the surrounding conditions are, at the time of inspection, perfectly satisfactory, it should be avoided, as trouble will arise in this class of work sooner than in any other, when all conditions are equal.

Insulated Metal Conduits — (Specifications). The metal covering or pipe should be of sufficient thickness to resist penetration by nails, etc., or the same thickness as ordinary gas pipe of the same size.

It should not be seriously affected externally by burning out a wire inside the tube when the iron pipe is connected to one side of the circuit.

The insulating lining should be firmly attached to the pipe, and should not crack or break when a length of conduit is uniformly bent at a temperature of 212 degrees Fahrenheit, to an angle of 90 degrees, with a curve having a radius of 15 inches, for pipes of 1 inch or less, or a radius of fifteen times the diameter of the pipe for larger sizes.

The insulating lining should not soften injuriously at a temperature below 212 degrees Fahrenheit, and should leave water in which it has been boiled, practically neutral.

The insulating lining should be at least one-thirty-second of an inch in thickness; and the materials of which it is composed should be of such a nature as will not have a deteriorating effect on the insulation of the conductor, and be sufficiently tough and tenacious to withstand the abrasion test of drawing in and out of some long lengths of conductors.

The insulating lining should not be mechanically weak after three days' submersion in water, and, when removed from the pipe entire, should not absorb more than ten per cent of its weight of water during 100 hours of submersion.

All elbows should be made for the purpose, and not bent from lengths of pipe. The radius of the curve of the inner edge of any elbow should not be less than three and one-half inches.

There should not be more than the equivalent of four quarter bends from outlet to outlet, the bends at outlets not being counted.

Each length of conduit, whether insulated or uninsulated, should have the maker's name or initials stamped in the metal or attached to it in some satisfactory manner, so that it may be readily seen, thus rendering it possible to place the responsibility for pieces not up to standard.

Uninsulated Metal Conduits or plain iron or steel pipes may be used instead of the insulated metal conduits, if made equally as strong and thick as the ordinary form of gas pipe of the same size, provided their interior surfaces are smooth and free from burrs. To prevent oxidation, the pipe should be galvanized, or the inner surfaces coated or enameled with some substance which will not soften so as to become sticky and prevent the wire from being withdrawn from the pipe. Elbows must be made for the purpose, and not bent from lengths of pipe. The radius of curves and number of bends from outlet to outlet should be the same as given under Insulated Metal Conduits. This bare iron or steel pipe should never contain any but a special extra insulated wire as hereinafter described:

Conduit Wire for Insulated Metal Conduits, whether single or twin conductors, should be standard rubber-covered wire as described on page 35; and where concentric wire is used in insulated metal conduits, it should have a braided covering between the outer conductor and the insulation of the inner conductor, and in addition should comply with and be able to withstand the test of standard rubber-covered wire.

Conduit Wire for Uninsulated Metal Conduits should not only have a standard rubber insulation as required for Insulated Metal Conduits, but in addition should have a second outer fibrous covering at least one-thirty-second inch in thickness, and sufficiently tenacious to withstand the abrasion of being hauled through the metal conduit. When concentric conductors are to be used in uninsulated metal conduits, they not only should comply with the requirements when used in insulated metal conduits, but, in addition, should have a second outer fibrous covering at least one-thirty-second of an inch in thickness and sufficiently tenacious to withstand the abrasion of being hauled through the metal conduit.

Interior Conduit Installation. All conduits should be continuous from one junction box to another or to fix' ' the conduit tube should properly enter all fittings, otherwise the conductors are not perfectly protected, and water is much more liable to gain an entrance into the conduit. No conduit with an inside diameter of less than five-eighths inch should be used.

The entire conduit system for a building should be completely installed before a single wire is drawn in; and all ends of conduits should extend at least one-half inch beyond the finished surface of walls or ceilings, except that, if the end is threaded and a coupling screwed on, the conduit may be left flush with the surface, and the coupling may be removed when work on the building is completed.

After all conductors have been drawn or pushed in, all outlets should be plugged up with special wood or fibrous plugs made in parts to fit around the wire, and the outlet then sealed with a good compound to keep out all moisture. All joints should be made air-tight and moisture-proof.

The metal of every conduit system should be effectually and permanently grounded. The conduit is likely to be more or less grounded, and a positive ground is necessary for the same reason that a positive ground is required for generator frames when it is impossible to insulate them perfectly.

Conduit Wiring. The reason why standard rubber covered wire, and not weatherproof, should be used in conduits, is that the best possible insulation is desirable for this class of work, as the insulating lining of the conduit may be defective in places, and there is a possibility of dampness getting into the conduit.

No wires should be drawn in until all mechanical work on the building is done.

Wires of different circuits should not be drawn in the same conduit.

For alternating systems, the two or more wires of a circuit should be drawn in the same conduit, in order to avoid trouble from inductive losses, which, under certain conditions, would cause a heating of the iron conduit to a dangerous degree. This trouble from induction becomes very much less if the wires are in the same conduit; less still, if the wires are twisted together; and disappears almost entirely if concentric wire is used.

Even in direct-current work it is advisable to place the two wires of a circuit in the same conduit, as in so doing the direct current may be changed for the alternating current without the necessity of rewiring, which would be necessary if only a single wire were placed in a conduit.

Fixtures, when supported from the gas piping of a building, should be insulated from the gas-pipe system by means of approved insulating joints placed as close as possible to the ceiling, and the wires near the gas pipe above the insulating joint should be protected from possible contact by the use of porcelain tubes.

All burrs or fins should be removed from the fixtures before the wires are drawn in. The tendency to condensation within the pipes should be guarded against by sealing the upper end of the fixture.

In combination fixtures, where the wiring is concealed between the inside pipe and outer casing, the space between pipe and casing should be at least a quarter of an inch to allow plenty of room for the insulation of the wires without jamming.

Fixtures should be tested for "contacts" between conductors and fixtures, for "short circuits" and for ground connections, before being connected to the supply conductors.

Ceiling blocks of fixtures should be made of insulating material; if not, the wires in passing through the plate should be surrounded by porcelain tubes.

Rosettes. These fittings should not be located where inflammable flyings or dust will accumulate on them. Bases should be high enough to keep the wires and terminals at least one-half inch from the surface to which the rosette is attached.

Terminals with a turned up lug to hold the wire or cord should be used, and in no case must the wire be cut or injured. Fused rosettes are not advised for use where cords can be properly protected by line cut-outs. If fused rosettes are used, the next fuses back should not be over 25 amperes capacity.

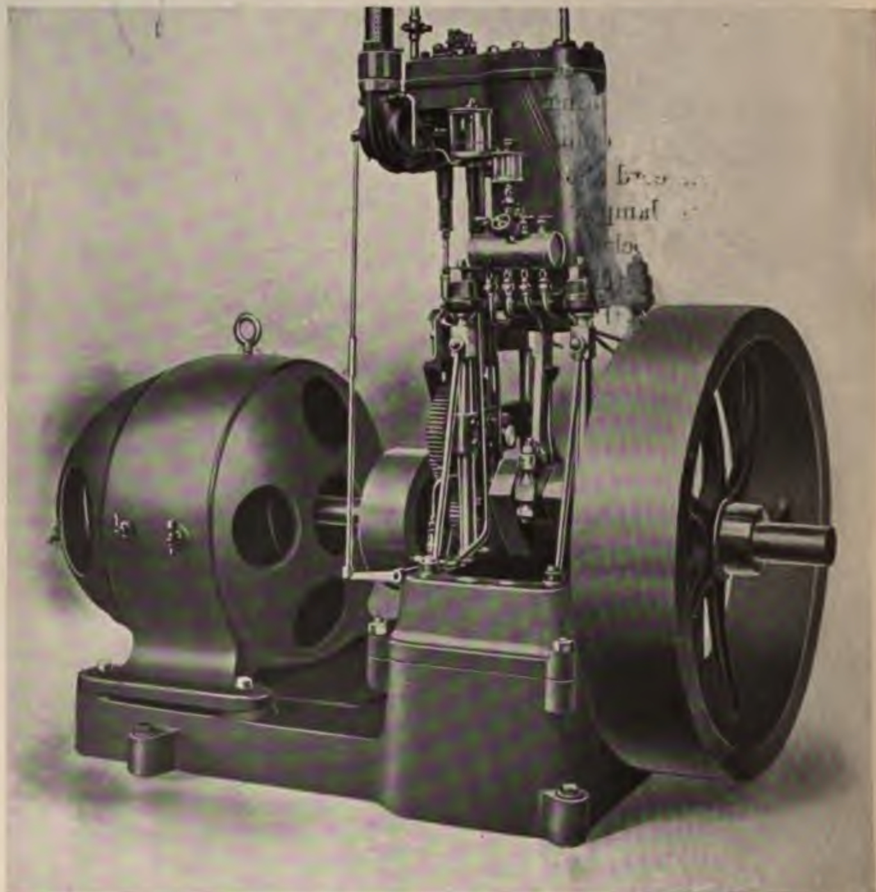
Fixture Wiring should be done with fixture wire, which has a solid insulation with a slow-burning, tough, outer covering, the whole at least one-thirty-second of an inch in thickness, and having an insulation resistance between conductors, and between either conductor and the ground, of at least one megohm per mile, after one week's submersion in water at 70 degrees Fahrenheit, and after three minutes' electrification with 550 volts.

Although No. 18 (B. & S. gauge) is allowable in fixture work, it is never advisable to use smaller than No. 16, for mechanical reasons. Supply conductors, and especially the splices to fixture wires, should be kept clear of the grounded part of gas pipes, and where shells are used the latter should have area enough to prevent pressing the wires against the gas pipe when finally in place. Where fixtures are wired on the outside, it is advisable to use cord for attaching the wires to the fixture, and not short bits of wire, as the latter might produce a short circuit or ground.

Flexible Cord should be made of a number of copper strands; no single strand should be larger than No. 26 or smaller than No. 30 (B. & S. gauge), and each conductor should be covered by an approved insulation and be protected from mechanical injury by a tough, braided, outer covering. When used for pendant lamps it should hang freely in air and be so placed that there is no chance of its coming in contact with anything excepting the lamp socket to which it is attached and the rosette from which it hangs. Each stranded conductor should have a carrying capacity equivalent to not less than a No. 18 (B. & S. gauge) wire. The covering of the stranded wires for flexible cord should first have a tight, close wind of fine cotton, which is intended to prevent any broken strand from piercing the insulation and causing a short circuit or ground. Secondly, it should have a solid waterproof insulation at least one-thirty-second of an inch thick, and should show an insulation resistance of 50 megohms per mile throughout two weeks' submersion in water at 70 degrees Fahrenheit. The outer protecting braiding should be so put on and sealed in place that when cut it will not fray out.

Flexible cord should not be used as a support for clusters, as it is not strong enough, and it should never be used for anything other than pendants, wiring of fixtures and portable lamps, portable motors, or small, light electrical apparatus.

Flexible cord should never be used in show windows, as a



5 KILOWATT, 80 LIGHT.

Secor Oil-Electric Generating Plant.

defective piece might cause a short circuit and set fire to flimsy material or decorations. Many fires have been caused by the use of flexible cord in show windows, where handkerchiefs, decorations, etc., have been pinned to the cord. When the current is "turned on" short circuits are caused by the pins, and a fire is the result.

Insulating bus s should be used where cords enter lamp sockets and desk s lamps.

Flexible co uld be so suspended that the entire weight of the socket, nd shade will be borne by knots under the bushing in the so , and above the point where the cord comes ough the ceiling block or rosette, in orde at the strain may be taken from the joints and binding screws. It is good practice always to solder the ends of flexible cords which are going under binding screws, as it holds the strands together and prevents the pressure of the screws from forcing the strands from under them and against the shell of the socket, causing a grounded shell or short circuit.

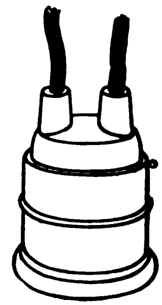


Fig. 11.
Waterproof keyless socket, to be used in dye houses or damp places.

Where it becomes necessary to solder a great number of ends, as may be required when wiring a factory, use a small pot of melted solder and dip the ends of the wire, which have all been previously cut to the proper length.

Standard Lamp Sockets should be plainly marked 50 candle-power, 250 volts, and with either the manufacturer's name or registered trade mark. The inside of the shell of the socket should have an insulating lining which should absolutely prevent the shell from becoming part of the circuit, even though a wire or strand inside the socket should become loose or come out from under a binding screw. This insulating lining should be at least one-thirty-second of an inch thick and of a tough and tenacious material.

Special Lamp Sockets. In rooms where inflammable gases may exist, both the socket and lamp should be enclosed in a vapor-tight globe, supported on a pipe-hanger, and wired with "Rubber-

Covered" wire soldered directly to the circuit. No fuses or switches of any sort should be used in such cases, as the slightest arc might produce dangerous explosions or fires. See Fig. 11.

In damp or wet places, such as dye houses, breweries, etc., a waterproof socket such as shown on page 51 should be used. Waterproof sockets should be hung by separate stranded rubber-covered wires, not smaller than No. 14 (B. & S.). These wires should be soldered direct to the circuit wires, but supported independently of them. All sockets for the above conditions should be keyless.

Stranded Wires in every case should be soldered together before being clamped under binding screws, and when they have a conductivity greater than No. 10 (B. & S.) copper wire they should be soldered into lugs. Stranded wires if not thus stiffened before being clamped under binding posts, are liable to be pressed out or easily worked loose, making a poor contact, which causes heating, a possibility of arcing or a complete burn out, or fusing of the wire at this point.

Bushings. All wires should be protected when passing through walls, partitions or floors, by non-combustible, non-absorptive insulating tubes, such as glass or porcelain. Each bushing should be long enough to go clear through and allow a projection of at least a quarter of an inch on both ends. Bushings should be long enough to bush the entire length of the hole in one continuous piece; or else the hole should first be bushed by a continuous waterproof tube, which may be a conductor, such as iron pipe, and the tube then should have a non-conducting bushing pushed in at each end so as to keep the wire absolutely out of contact with the conducting pipe.

Automatic Cut-outs such as circuit breakers and fuses should be placed on all service wires as near as possible to the point where they enter the building, on the inside of the walls, and arranged to cut off the entire current from the building.

The cut-out or circuit breaker should always be the first thing that the service wires are connected to after entering the building; the switch next, and then the other fixtures or devices in their order. This arrangement is made so that the cut-out or circuit breaker will protect all wiring in the building, and the opening of the switch will disconnect all the wiring.

These automatic cut-outs should not, however, be placed in the immediate vicinity of easily ignitible stuff, nor where exposed to inflammable gases or dust, or to flyings of combustible material, as the arcing produced whenever they break the circuit might cause a fire or explosion. When they are exposed to dampness they should be inclosed in a waterproof box or mounted on porcelain knobs. All cut-outs and circuit breakers should be supported on bases of non-combustible, non-absorptive insulating material. Cut-outs should be provided with covers when not arranged in approved cabinets, so as to obviate any danger of the melted fuse metal coming in contact with any ignitible substance.

Cut-outs should operate successfully under the most severe conditions they are liable to meet with in practice, on short circuits, with fuses rated at 50 per cent above, and with a voltage 25 per cent above, the current and voltage for which they are designed. Circuit breakers should also be designed to operate successfully under the severe conditions liable to be met with in practice, or at 50 per cent above the current and with a voltage of 25 per cent above that for which they are designed. All cut-outs and circuit breakers should be plainly marked, and where it will always be visible, with the name of the maker as well as the current and voltage for which the device is designed.

Cut-outs or circuit breakers should be placed at every point where a change is made in the size of wire, unless such a device in the larger wire will protect the smaller. They should never be placed in canopies or shells of fixtures, but should be so placed that no set of incandescent lamps, whether grouped on one fixture or several fixtures or pendants, requiring a current of more than six amperes, should be dependent upon one cut-out. Special permission may be given in writing by the Inspection Department having jurisdiction, in case extra large or special chandeliers are to be used. Fused rosettes, when used with flexible cord pendants, are considered as equal to a cut-out. Fuses for cut-outs should not have a capacity to exceed the carrying capacity of the wire; and where circuit breakers are used they should not be set more than 30 per cent above the allowable carrying capacity of the wire, unless a fusible cut-out is also installed in the circuit.

Circuit breakers open at exactly the current they are set for, and instantly; therefore it is necessary to get them considerably above the ordinary amount of current required, to keep them from constantly opening on slight fluctuations. When this is the case a double-pole fusible cut-out should be added to protect the wire from a heavy, steady current, which may be maintained just below the opening point of the circuit breaker. The fuse requires a little time to heat, and therefore would not blow out with a momentary rise of current which might open the circuit breaker if set as low as necessary to protect the wire, which may be of a size only large enough for the figured amount of current under ordinary conditions of operation. If, however, in the case of motor wiring, the size of wire is 50 per cent above the figured size for the motor's average current, as it should be, then the introduction of a fusible cut-out in addition to the circuit breaker is unnecessary.

Insulating Joints should be made entirely of material that will resist the action of illuminating gases, and that will not give way or soften under the heat of an ordinary gas flame, or leak under a moderate pressure.

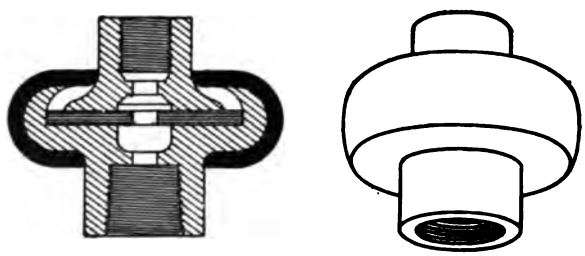


Fig. 12.
The Macallen Insulating Joint.

They should be so arranged that a deposit of moisture will not destroy the insulating effect, and should have an insulation resistance of at least 250,000 ohms between the gas pipe attachments, and be sufficiently strong to resist the strain they will be liable to be subjected to in being installed.

Insulating joints should not contain any soft rubber in their composition. The insulating material should be of some hard and durable material, such as mica. See Fig. 12.

Insulation Resistance. The wiring in any building should test free from grounds, *i. e.,* the complete installation should have an insulation between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.), of not less than the following:

Up to—	
5 amperes	4,000,000
10 amperes	2,000,000
25 amperes	800,000
50 amperes	400,000
100 amperes	200,000
200 amperes	100,000
400 amperes	50,000
800 amperes	25,000
1,000 amperes	12,500

All cut-outs and safety devices in place in the above.

Where lamp sockets, receptacles and electroliers, etc., are connected, one-half of the above will be required.

Knife Switches. Switches should be placed on all service wires, either overhead or underground, in a readily accessible place, as near as possible to the point where the wires enter the building, and arranged to cut off the entire current.

Knife switches should always be installed so that the handle will be up when the circuit is closed, so that gravity will tend to open rather than close the switch. They should never be single-pole except when the circuit which they control is carrying not more than six 16-candle-power lamps or their equivalent.

Double-pole switches are always preferable to single-pole, as they absolutely disconnect the part of the circuit out of use.

Flush Switches. Where gangs of flush switches are used, whether with conduit systems or not, the switches should be enclosed in boxes constructed of, or lined with, fire-resisting material.

Where two or more switches are placed under one plate, the box should have a separate compartment for each switch. No push buttons for bells, gas lighting circuits, or the like, should be placed in the same wall plates with switches controlling electric light or power wiring.

Snap Switches, like knife switches, should always be mounted on non-combustible, non-absorptive, insulating bases, such as slate or porcelain, and should have carrying capacity sufficient to prevent undue heating.

When used for service switches they should indicate at sight whether the current is "on" or "off." Indicating switches should be used for all work, to prevent mistakes and possible accidents. The fact that lights do not burn or the motor does not run is not necessarily a sure sign that the current is off.

Every switch, like every piece of electrical apparatus, should be plainly marked, where it is always visible, with the maker's name and the current and voltage for which it is designed.

On constant-potential systems, these switches, like knife switches, should operate successfully at 50 per cent overload in amperes with 25 per cent excess voltage, under the most severe conditions they are likely to meet with in practice. They should have a firm contact, should make and break readily, and not stop when motion has once been imparted to the handle. When this style of switch is used for constant-current systems, they should close the main circuit and disconnect the branch wires when turned "off;" should be so constructed that they will be automatic in action, not stopping between points when started; and should prevent an arc between the points under all circumstances. They should also indicate at sight whether the current is "on" or "off."

Incandescent Lamps. Table X is compiled from a series of careful tests on a number of incandescent lamps taken from a large stock at random.

Poor regulation of voltage results in more trouble with incandescent lamps and their users than any other fault in electric lighting service.

Some men act on the theory that so long as the life of a lamp is satisfactory, an increase of voltage, either temporary or permanent, will increase the average light. The fact is that when lamps are burned above their normal rating the average candle-power of all the lamps on the circuit is decreased.

Excessive voltage is thus a double error—it decreases the

TABLE X.
Incandescent Lamp Data.

VOLTS.	C. P.	Amp.	Watts Per Lamp.	Watts Per C. P.	Hot Res.
52	10	.67	35	3.50	77.61
"	16	1.08	56	"	48.14
"	20	1.34	70	"	38.80
"	24	1.62	84	"	32.09
"	32	2.15	112	"	24.18
"	50	3.36	175	"	15.47
"	100	6.73	350	"	7.72
"	150	10.09	525	"	5.15
104	10	.34	35	3.50	305.88
"	16	.54	56	"	192.59
"	20	.67	70	"	185.22
"	24	.81	84	"	128.39
"	32	1.08	112	"	96.29
"	50	1.68	175	"	61.90
"	100	3.36	350	"	30.95
"	150	5.05	525	"	20.59
110	10	.32	35	3.50	343.75
"	16	.51	56	"	215.68
"	20	.64	70	"	171.87
"	24	.76	84	"	144.73
"	32	1.02	112	"	107.84
"	50	1.59	175	"	691.82
"	100	3.18	350	"	34.59
"	150	4.77	525	"	23.06
220	16	.291	64	4.00	756.01
"	32	.582	128	"	379.31

total light of the lamps, and increases the power consumed. If increased light is needed, 20-candle-power lamps should be installed instead of raising the pressure. Their first cost is the same as 16-candle-power lamps; they take but little more current than 16-candle-power lamps operated at high voltage and give greater average light.

Increased pressure also decreases the commercial life of the lamp, and this decrease is at a far more rapi the increase of pressure, as shown in the following t shows the decrease in life of standard 3.1-watt lamps due to increase of normal voltage.

Per Cent of Normal Voltage.	Life Factor.
100	1.000
101	.818
102	.681
103	.662
104	.452
105	.374
106	.310

From this table it is seen that 3 per cent increase of voltage halves the life of a lamp, while 6 per cent increase reduces the life by two thirds.

Intensity or Brilliancy. The average brilliancy of illumination required will depend on the use to which the light is put. A dim light that would be very satisfactory for a church would be wholly inadequate for a library and equally unsuitable for a ballroom.

The illumination given by one candle at a distance of one foot is called the "candle-foot" and is taken as a unit of intensity. In general, intensity of illumination should nowhere be less than one candle-foot, and the demand for light at the present time quite frequently raises the brilliancy to double this amount. As the intensity of light varies inversely with the square of the distance, a 16-candle-power lamp gives a candle-foot of light at a distance of four feet. A candle-foot of light is a good intensity for reading purposes.

Assuming the 16-candle-power lamp as the standard, it is generally found that two 16-candle-power lamps per 100 square feet of floor space give good illumination, three very bright and four brilliant. These general figures will be modified by the height of ceiling, color of walls and ceiling, and other local conditions. The lighting effect is reduced, of course, by an increased height of ceiling. A room with dark walls requires nearly three times as many lights for the same illumination as a room with walls painted white. With the amount of intense light available in arc and incandescent lighting, there is danger of exceeding "the limits of effective illumination" and producing a "glaring intensity" which should be avoided as carefully as too little intensity of illumination.

Distribution concerns the arrangement of the various sources of light and the determination of their candle-power. The object should be to "secure a uniform brilliancy on a certain plane, or within a given space. A room uniformly lighted, even though comparatively dim, gives an effect of much better illumination than where there is great brilliancy at some points and comparative darkness at others. The darker parts, even though actually light enough, appear dark by contrast, while the lighter parts are dazzling. For this reason naked lights of any kind are to be avoided, since they must appear as dazzling points in contrast with the general illumination."

The Arrangement of the Lamps is dependent very largely upon existing conditions. In factories and shops, lamps should be placed over each machine or bench so as to give the necessary light for each workman. In the lighting of halls, public buildings and large rooms, excellent effects are obtained by dividing the ceilings into squares and placing a lamp in the center of each square. The size of square depends on the height of ceiling and on the intensity of illumination desired. Another excellent method consists in placing the lamps in a border along the walls near the ceiling.

For the illumination of show windows and for display effects, care must be taken to illuminate by reflected light. The lamps should be so placed as to throw their rays upon the display without casting any direct rays on the observer.

The relative value of high candle-power lamps in comparison with an equivalent number of 16-candle-power lamps is worthy of notice. Large lamps can be efficiently used for lighting large areas, but in general a given area will be much less effectively lighted by high candle-power lamps than by an equivalent number of 16-candle-power lamps. For example, sixteen 64-candle-power lamps distributed over a large area will not give as good general illumination as sixty-four 16-candle-power lamps distributed over the same area. High candle-power lamps are useful chiefly when a brilliant light is needed at one point, or where space is limited and an increase in illuminating effect is desired.

The Relative Value of the Arc and Incandescent Systems of Lighting is frequently difficult to determine. Incandescent

TABLE XI.

Tested Fuse Wire.

CHASE-SHAWMUT CO.,
Boston.

Carrying Capacity. Amperes.	Standard Length. Inches.	Diameter in Mils.	Feet Per Pound.
¼	1½	10	2,700
½	1½	17	950
1	1½	20	670
1½	1½	23	510
2	1½	25	430
3	1½	27	370
4	1½	30	300
5	2	35	312
6	2	38	504
7	2	44	021
8	2	47	120
9	2	54	93
10	2	58	80
12	3	62	70
14	3	68	60
15	3	70	52
16	3	73	49
18	3	78	43
20	4	86	36
25	4	90	32
30	4	100	26
35	4	110	22
40	4	122	18
45	4	126	17
50	4	147	12.5
60	5	160	10.3
70	5	172	9.0
75	5	178	8.3
80	5	190	7.5
90	5	198	6.7
100	5	220	5.5

lamps have the advantage that they can be distributed so as to avoid the shadows necessarily cast by one single source of light. Arc lamps used indoors with ground or opal globes cutting off half the light, have an efficiency not greater than two or three times that of an incandescent lamp. Nine 50-watt, 16-candle-power lamps consume the same power as one full 450-watt arc lamp. It has been found that unless an area is so large as to require 200 or 300 incandescent lights distributed over it, arc lamps requiring equal total power will not light the area with so uniform a brilliancy.

Fuses should have contact surfaces or tips of harder metal, having perfect electrical connection with the fusible part of the strip.

The use of the hard metal tip is to afford a strong mechanical bearing for the screws, clamps or other devices provided for holding the fuse.

Fuses should be stamped with about 80 per cent of the maximum current they can carry indefinitely, thus allowing about 25 per cent overload before the fuse melts.

With naked open fuses of ordinary shapes and not over 500 amperes capacity, the maximum current which will melt them in about five minutes may be safely taken as the melting point, as the fuse practically reaches its maximum temperature in this time. With larger fuses a longer time is necessary.

The following table shows the minimum break distance, and the separation of the nearest metal parts of opposite polarity, for open-link fuses when mounted on slate or marble bases, for different voltages and different currents:

	Separation of nearest metal parts of opposite polarity.	Minimum break distance.
125 Volts or Less.		
10 amperes or less	¾ inch	¾ inch
11—100 amperes	1 inch	¾ inch
101—300 amperes	1 inch	1 inch
125 to 250 Volts.		
10 amperes or less	ʰ	1¼ inch
11—100 amperes		1¼ inch
101—300 amperes		inch

Fuse Terminals shou[illegible] 's name or initials, or some know[illegible]

Fuse Wire. Table XI shows the sizes of fuse wire and the approximate current-carrying capacity of each size.

Fuses have been known to blow out simply from the heat due to poor contact when nowhere near their current-carrying capacity had been reached. They should be so put up and protected that nothing will tend to rupture them except an excessive flow of current. No fuse of the larger sizes ever blew out without causing a greater or less fire risk.

Fuses blow out or melt from excessive heat, and nothing else, and are therefore not as instantaneous in their action as a circuit breaker, which is constantly cared for and kept clean. Central stations or large isolated plants subject to greatly varying loads should have their lines and generators protected by both fuses and magnetic circuit breakers as a double protection against excessive current.

The lengths of fuses and distances between terminals are important points to be considered in the proper installation of these electrical "safety valves." No fuse block should have its terminal screws nearer together than one inch on 50 or 100-volt circuits, and one inch additional space should always be allowed between terminals for every 100 volts in excess of this allowance. For example, 200-volt circuits should have their fuse terminals 2 inches apart, 300-volt 3 inches, and 500-volt 5 inches. This rule will prevent the burning of the terminals on all occasions of rupture from maximum current, and this maximum current means a "short circuit." Good contact is absolutely essential in the installation and maintenance of fuses. See that the copper tips to all fuses are well soldered to the fuse wire, and furthermore see that the binding screw or nut is firmly set up against this copper tip when the fuse is placed in circuit; a 100-ampere fuse can be readily "blown" by 25 amperes if the above precautions are not carried out. Poor contact in every case can cause a heating beyond the carrying capacity of the largest fuses. On the other hand, much damage can be done by using too short fuses and too large terminals, as the radiation of heat from the short piece of fuse wire to the heavy metal terminals and set screws or nuts can very easily raise the current-carrying capacity of a fuse designed to carry 50 amperes to 100 amperes, or even more. All open-link fuses should be placed in cut-out cabinets when possible.

Cut-out Cabinets should be so constructed, and cut-outs so arranged, as to obviate any danger of the melted fuse metal coming in contact with any substance which might be ignited thereby.

A suitable box may be made of marble, slate or wood, strongly put together, the door to close against a rabbet so as to be perfectly dust tight, and it should be hung on strong hinges and held closed by a strong hook or catch. If the box is wood the inside should be lined with sheets of asbestos board about one-sixteenth of an inch in thickness, neatly put on and firmly secured in place by shellac and tacks. The wires should enter through holes bushed with porcelain bushings, the bushings tightly fitting the holes in the box, and the wires tightly fitting the bushings (using tape to bind up the wire, if necessary), so as to keep out the dust.

The Enclosed Fuse, or "Cartridge Fuse" (see Fig. 13), consists of a fusible strip or wire placed inside of a tubular holding jacket filled with porous or powdered insulating material through which the fuse wire is suspended from end to end and which surrounds the fuse wire. The wire, tube and filling are made into one complete, self-contained device with brass or copper terminals or ferrules at each end, the fuse wire being soldered

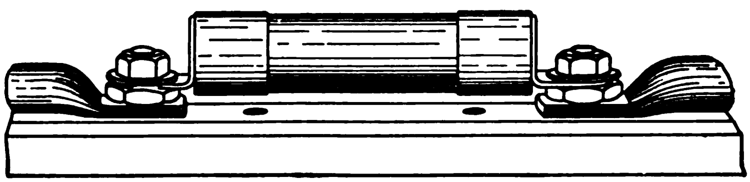


Fig. 13.
Enclosed Fuse.

to the inside of the ferrules. When an inclosed fuse "blows" by excess current or short circuit the gases resulting are taken up by the filling, the explosive tendency is reduced and flashing and arcing are eliminated.

Incandescent Lamps in Series Circuits should be wired with

TABLE XII.

Dimensions of Enclosed Fuses.

By Joseph Sachs.

VOLTS	Class, Amps.	Tube Length, Inches.	Tube Diam., Inches.	Fuse Length, Inches.	VOLTS	Class, Amps.	Tube Length, Inches.	Tube Diam., Inches.	Fuse Length, Inches.	VOLTS	Class, Amps.	Tube Length, Inches.	Tube Diam., Inches.	Fuse Length, Inches.
220	1–8	2 3/16	3/8	1	500	1–10	4 5/8	3/8	3	2,500	1–12	5 1/4	1/2	4 1/2
	10–15	2 11/16	3/8	1		12–25	5 1/4	1/2	3 1/4		15–30	5 1/4	5/8	4 1/2
	20–30	3 3/16	1/2	1 1/4		30–50	5 3/4	3/4	3 1/2		35–50	6 1/4	7/8	5
	35–50	3 3/4	3/4	1 1/2		60–100	6 1/4	1	3 1/2		60–75	6 15/16	1 1/8	5 5/8
	60–100	4 1/8	7/8	1 1/2		125–150	6 1/4	1 1/4	3 5/8		80–100	6 15/16	1 1/4	5 5/8
	125–150	4 1/8	1	1 3/4		175–225	6 7/16	1 1/2	3 3/4					
	175–225	4 11/16	1 1/4	2 1/2		250–400	6 5/8	2	3 7/8					
	250–400	4 13/16	1 1/2	2 1/2		500–600	10	2 1/2	4					
	500–600	6 3/16	2	2 1/2										
5,000	1/2–12	15 1/8	3/4	13	10,000	1/2–12	24	3/4	18	20,000	1/4–10	30	1	24
	15–30	15 1/8	1	13		15–30	24	1	18					
	35–50	18 1/8	1 1/8	14										

the same precaution as for series arc lighting and each lamp should be provided with an automatic cut-off.

Each lamp should be suspended from an approved hanger board by means of a rigid tube, to prevent the wires from constant swinging.

No electro-magnetic device for switches and no system of multiple, series, or series-multiple lighting in this class of work should be used. Under no circumstances should incandescent lamps in series circuits be attached to gas fixtures, as the high voltage necessarily employed in this class of lighting should be kept as far as possible from gas piping, which is so thoroughly grounded or likely to be.

When incandescent lamps are used for decorative purposes, as in the use of miniature colored lamps, and it is necessary to run two or more in series, permission should always be secured, in writing, from the Inspection Department having jurisdiction.

Arc Lamps should be carefully isolated from inflammable material, should be provided at all times with a glass globe surrounding the arc and securely fastened upon a closed base. No broken or cracked globes should be used, as they are designed to prevent hot bits of carbon from falling to the floor should they fall from the carbon holder. All globes for inside work should be covered with a wire netting having a mesh not exceeding one and one-quarter inches, to retain the pieces of the globe in position should the latter become broken from any cause. A globe thus broken should be replaced at once. When arc lamps are used in rooms containing readily inflammable material they should be provided with approved spark arresters, which should be made to fit so closely to the upper orifice of the globe that it would be impossible for any sparks thrown off by the carbons to escape. It is safer to use plain carbons and not copper-plated ones in such rooms, or better still, an enclosed arc lamp, one having its carbons enclosed in a practically tight glass globe which is inside the outer globe. Where hanger-boards are not used arc lamps should be hung from insulating supports other than thei[illegible]tors.

All arc lamps should be provided with rel[illegible] vent carbons from falling out in case the [illegible] and all exposed parts should be carefully insulated from the circuit. Each lamp for constant-current systems should be provided with an approved hand switch, and also an automatic switch that will shunt the current around the carbons, so that the lamp will thus cut itself out of circuit should the carbons fail to feed properly. If the hand switch is placed anywhere except on the lamp itself, it should comply in every respect with the requirements for switches on hanger-boards as described under the latter heading.

Arc Light Wiring. All wiring for high-potential arc lighting circuits should be done with "Rubber-Covered" wire. The wires should be arranged to enter and leave the building through an approved double-contact service switch, which should close the main circuit and disconnect the wires in the building when turned "off." These switches should be so constructed that they will be automatic in their action, not stopping between points when started, and preventing arcing between points under any circumstances, and should indicate plainly whether the current is "on" or "off." Never use snap switches for arc lighting circuits. All arc light wiring of this class should be in plain sight and never enclosed except when required, and should be supported on porcelain or glass insulators which separate the wires at least one inch from the surface wired over. The wires should be kept rigidly at least eight inches apart, except of course within the lamp, hanger-board, or cut-out box or switch. On side walls the wiring should be protected from mechanical injury by a substantial boxing retaining an air space of one inch around the conductors, closed at the top (the wires passing through bushed holes), and extending not less than seven feet above the floor. When crossing floor timbers in cellars or in rooms, where they might be exposed to injury, wires should be attached by their insulating supports to the under side of a wooden strip not less than one-half an inch in thickness.

Arc Lamps on Low-Potential Circuits should have a cut-out for each lamp or series of lamps. The branch conductors for such lamps should have a carrying capacity about 50 per cent in excess of the normal current required by the lamp or lamps, to provide for the extra current necessary when the lamps are started, or, should a carbon become stuck, to prevent over-fusing the wires. If any resistance coils are necessary for adjustment or regulation, they should be enclosed in non-combustible material and be treated as sources of heat; it is preferable that such resistance coils be placed within the metal framework of the lamp itself. Incandescent lamps should never be used for resistance devices. These lamps should be provided with globes and spark arresters, as in the case of arc lamps on high-potential series circuits, except when the enclosed arc lamps are used.

Economy Coils, or compensator coils, for arc lamps should be mounted on glass or porcelain, allowing an air space of at least one inch between frame and support, and in general should be treated like sources of heat.

Hanger-Boards should be so constructed that all wires and current-carrying devices thereon will be exposed to view and thoroughly insulated on non-combustible, non-absorptive insulating substance, such as porcelain.

All switches attached to the hanger-board should be so constructed that they will be automatic in their action, cutting off both poles to the lamp, not stopping between points when started, and preventing an arc between points under all circumstances.

Electric Heaters should always be treated as sources of heat and kept away from inflammable materials. Each heater should have a cut-out and indicating switch, and all attachments from the feed wires to the heater should be kept in plain sight, easily accessible and protected from interference. Each heater should have a name-plate giving the maker's name and the normal capacity in volts and amperes.

Approved Apparatus and Supplies. Every article or fitting intended for use in electrical wiring or construction or in connection therewith should, before being manufactured or placed upon the market, be examined and approved by the Underwriters' National Electric Association for use under the rules and requirements of the National Board of Fire Underwriters and placed upon their official list of "approved" electrical fittings.

Any new article, therefore, or modification of an old article, intended to be placed in general electrical use, should first be se for examination and test to the laboratory of the Electri Bureau of the National Board of Fire Underwriters, 67 E Twenty-first street, Chicago, Ill.

If the article is approved it will be placed upon the list fittings, which list is revised quarterly. When buying electri supplies of any description make sure that they have been a proved. If there is any question about it, make your sup dealer give you a guarantee that they will be approved by t Fire Underwriters' Inspector if installed in accordance with t rules and requirements of the National Board of Underwriters.

Electrical Inspection. The principal points regarding t safe installation of dynamos, motors, outside and inside wiri as required by the insurance underwriters, have been set forth this paper. There will probably arise questions which cam be settled by reference to the suggestions herein contained, a therefore a great deal has to be left to the judgment of the c structing engineer and inspector. In every such case the Insp tion Department having jurisdiction should be consulted w perfect assurance that nothing unreasonable will ever be demanc in the way of special construction.

Every piece of wiring or electrical construction wo whether open or concealed, should be and usually is inspect and notice, therefore, should always be sent by the contractor engineer to the board having jurisdiction, immediately upon co pletion of any work.

Negligence in this matter has frequently caused floors to torn up when doubtful work has been suspected, and at the c of the parties who installed the wiring.

The insurance inspector cannot order any piece of wiri taken out or altered, but always reports whether or not the pl is installed in a manner which will reduce the fire risk to a mi mum. If the inspector has occasion to recommend any chan which he considers for the safety of the building, and su changes are not immediately made, he recommends that the ins ance rate on the building be so raised that it will, in the end, found advisable to attend to his suggestions, which are in ev case reasonable.

ELECTRIC BELL WIRING.

In wiring for electric bells to be operated by batteries, the danger of causing fires from short circuits or poor contacts does not exist as in the case of wiring for light and power, because the current strength is so small. Neither is the bell-fitter responsible to city inspectors or fire underwriters. On this account, bell fitting is too often done in a careless and slovenly manner, causing the apparatus to give unsatisfactory results and to require frequent repairs, so that the expense and inconvenience in the end far more than offset any time saved by doing an inferior grade of work. Hence, at the outset it is well to state that as much care should be taken in the matter of joints and insulation of bell wiring as in wiring for light or power.

If properly installed, the electric bell forms a reliable and yet inexpensive means of signaling, and is far superior to any other. On this account practically every new building is fitted throughout with electric bells.

In addition to the necessity of thoroughness already mentioned, care should be taken to use only reliable apparatus which must be installed in accordance with the fundamental principles on which its satisfactory operation depends.

WIRE.

The common sizes of wire in use for bell work are Nos. 18, 20, and 22. In general, however, No. 20 will be found satisfactory as it is usually sufficiently large, while in many cases No. 22 is not strong enough from a mechanical standpoint.

It is important that the wires should be well insulated to pre-

Fig. 1.

vent accidental contacts with the staples or other wires. all the wire should be tinned, as this prevents t' being acted upon by the sulphur in the insula' itates soldering. The inner coating of insu india rubber, surrounded by several longitudinal strands of cotton, outside of which are wound several strands of colored cotton laid on spirally. This is next immersed in melted paraffin wax and polished by friction. A short length of approved electric bell wire is shown in Fig. 1.

When ordering wire, it is well to have it furnished in several different colors as this greatly facilitates both the original installation and later repairs, because in this way one line may be distinguished from another, taps from main lines, etc. Moreover, a faulty wire having been found, it is possible to identify it at any desired section of its length.

METHODS OF WIRING.

In running wires, the shortest and most direct route should, of course, be taken between the battery, bells, and bell pushes. There are two cases to be considered. The better method is that in which the wires are run before the building is completed, and the wiring should be done as soon as the roof is on and the walls are up. In this case the wires are usually run in zinc tubes secured to the walls with nails. The tubes should be from $\frac{3}{8}$ inch to $\frac{1}{2}$ inch in diameter, preferably the latter. It is better to place the wires and tubes simultaneously, but the tubes may be put in place first and the wires drawn in afterward, although this latter plan has the objection that the insulation is liable to become abraded when the wires are drawn in. In joining up two lengths of tube, the end of one piece should be opened up with the pliers so that it may receive the end of the other tube, which should also be opened up, but to a less extent, to prevent wear upon the insulation. Specially prepared paper tubes are sometimes substituted for the zinc.

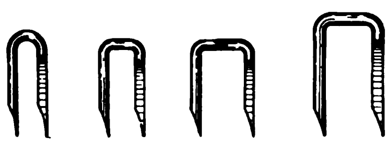


Fig. 2.

If the building is completed before the wiring is done, the concealed method described above cannot be used, and it is necessary to run the wires along the walls supported by staples, where they will be least conspicuous. Fig. 2 shows ordinary double-pointed tacks, Fig. 3 shows an insulating saddle staple which is to be recommended. Two wires should never be secured under the same staple if it can possibly be avoided, owing to the danger of short circuits. With a little care it is usually possible to conceal the wiring behind the picture moulding, along the skirting-board, and beside the door posts, but where it is impossible to conceal it, a light ornamental casing to match the finish of the room, may be used. It is sometimes advisable to use twin wires or two insulated wires run in the same outer covering.

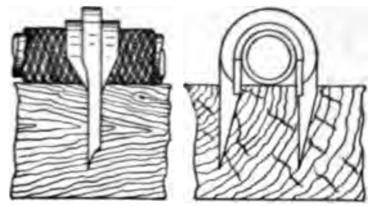


Fig. 3.

In some cases it is well to run the wires under the floors, laying them in notches in the tops of the joists or in holes bored about two inches below the tops of the joists.

JOINTS.

When making a joint, care should be taken to have a firm, clean connection, both mechanically and electrically, and this must always be soldered to prevent corrosion. The insulation should be stripped off the ends of the wires to be joined, for a distance of about 2 inches, and the wires made bright by scraping or sandpapering. They should then be twisted tightly and evenly together as shown in Fig. 4.

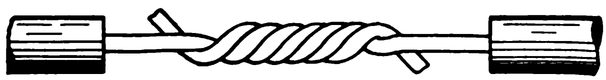


Fig. 4.

Next comes the operation of **soldering**, which is absolutely necessary if a permanent joint from an electrical standpoint is to be obtained. A joint made without solder may be electrically sound at first, but its resistance rapidly increases, due to deterioration of the joint. As has already been stated, the wires should be made bright and clean before they are twisted together. Soldering fluids should never be used, because they cause corrosion of the wire. The best flux to use is resin or composite candle. The soldering should always be done with a copper bit rather than with a blowpipe or wireman's torch.

A convenient form of soldering tool consists of a small copper bit having a semicircular notch near the end. This bit should, of course, be well tinned. It is then heated over a spirit lamp, or wireman's torch, and the notch filled with soft solder. Lay the joint, which has previously been treated with the flux, in this notch and turn it so that the solder runs completely around among the spirals of the joint. The loose solder should be shaken off or removed with a bit of rag. When the joint is set, it should be insulated with rubber tape, so that it will be protected as perfectly as the other portions.

It is often possible to save a considerable length of wire and amount of labor by using a ground return, which, if properly arranged, will give very satisfactory results, although a complete metallic circuit is always to be preferred. Where water or gas mains are available, a good ground may be obtained by connecting to them, being sure to have a good connection. This may be secured by scraping a portion of the pipe perfectly bright and clean and then winding this with bare wire; the whole is then well soldered. An end should be left to which the wire from the bell circuit is twisted and soldered. If such mains are not available, a good ground can be obtained by connecting the wire from the bell circuit, as described above, to a pump pipe. In the absence of water and gas mains, and of a pump pipe, a ground may be obtained by burying beneath permanent moisture level a sheet of copper or lead, having at least five square feet of surface, to which the return wire is connected. The ground plate should be covered with coke nearly to the surface; the hole should then be filled in with ordinary soil well rammed.

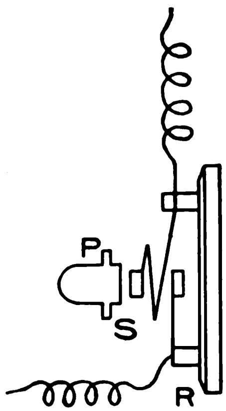


Fig. 5.

OUTFIT.

The three essential parts of the electric bell outfit are the bell push, which furnishes a means of opening and closing the circuit at will, the battery, which furnishes the current for operating the bell, and the bell itself. Before discussing the combination of these pieces of apparatus in the complete circuit, let us take up the individual parts in order.

A bell push is shown diagrammatically in Fig. 5. In this illustration P is the push button; when this is pressed upon it brings the point of the spring S in contact with the metal strip R, thus closing the circuit with which it is connected in series. Normally the springs are separated as shown, and the circuit is accordingly open.

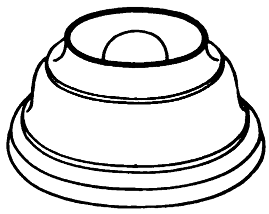


Fig. 6.

Bell pushes are made in various designs and styles, from the simple wooden push shown in Fig. 6 to very elaborate and expensive articles. Fig. 7 shows four cast bronze pushes of neat appearance and moderate price.

Batteries. Electric bells are nearly always operated on the open circuit plan, and hence the battery used is generally of the

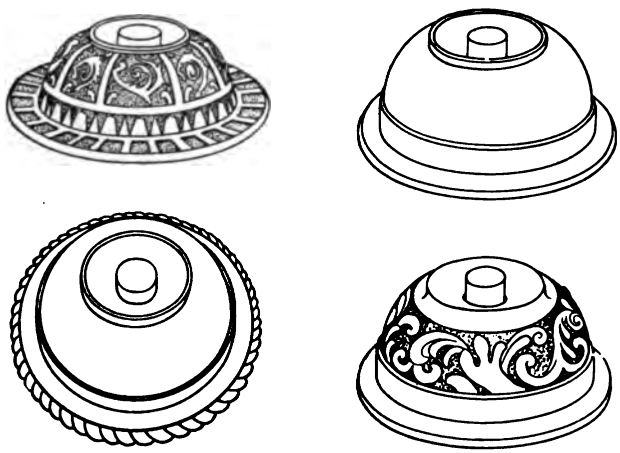


Fig. 7.

open circuit type, such as the Leclanche cell, which is used very largely except for heavy work. This is a zinc-carbon cell in which the excitant is sal-ammoniac dissolved in water. Polarization is prevented by peroxide of manganese, which gives up part of its oxygen, combining with the hydrogen set free and forming water.

Dry Batteries are also frequently used for bell work, their principal advantage being cleanliness, as they cannot spill. Dry cells are really a modification of the Leclanche type, as they use zinc and carbon plates and sal-ammoniac as the exciting agent. The Burnley cell, which is one of the principal types of dry cell, has an electrolyte composed of sal-ammoniac, chloride of zinc, plaster, flour, and water. This compound when mixed is a semi-liquid mass which quickly stiffens after being poured into the cup. The depolarizing agent is peroxide of manganese, the same as is used in the Leclanche cell, this being packed around the carbon cylinder. The top of the cell is sealed with bitumen or some similar substance.

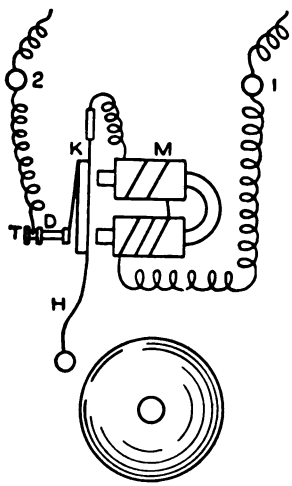


Fig. 8.

For very heavy work the Edison-Lalande and the Fuller types of cell are best suited, while for closed circuit work the gravity cell is most satisfactory.

Bell. It is a well-known fact that if a current of electricity flows through a coil of wire wound on an iron core, the core becomes magnetized and is capable of attracting any magnetic substances to itself. The operation of the electric bell, like that of so many other pieces of electrical apparatus, depends upon this fact. A diagrammatic representation of an electric bell is shown in Fig. 8, in which M is an electromagnet composed of soft-iron cores on which are wound coils of insulated wire. The armature is mounted upon a spring K, and carries a hammer H at its end for striking the gong. On the back of the armature is a spring which makes contact at D with the back stop T. The action of the bell is as follows: When the circuit is closed through the bell a current flows from terminal 1, around the coils of the magnet, through the spring K and contact point D, through the back stop T, to terminal 2. In flowing around the electromagnet the current magnetizes its core, which consequently attracts the armature. This causes the hammer H to strike the gong. While in this position the contact at D is broken, the current ceases to flow around the electromagnet and the cores consequently lose their attractive force. The armature is then carried back to its original position by the spring K, making contact at D, and the process is repeated. The hammer will thus vibrate and the bell continue to ring as long as the circuit is closed.

The type of bell described above is the one most commonly used. Such bells are made in a great variety of shapes and styles, the prices varying accordingly. It is important that platinum tips be furnished at the contact point D, Fig. 8, to prevent corrosion. The bells on the market today are of two classes, the iron box bell and the wooden box bell. A bell of the wooden box type is shown in Fig. 9, and a higher grade bell of the iron frame skeleton type is shown in Fig. 10. Bells without covers should never be used, as dust will settle on the contacts and interfere with their action.

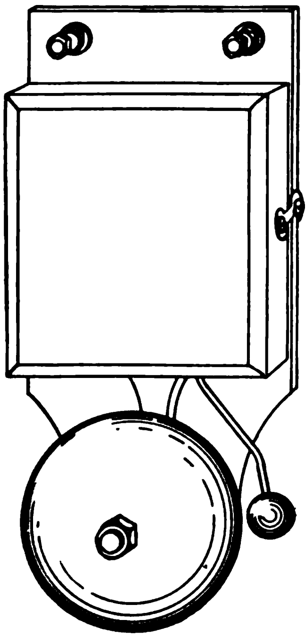


Fig. 9.

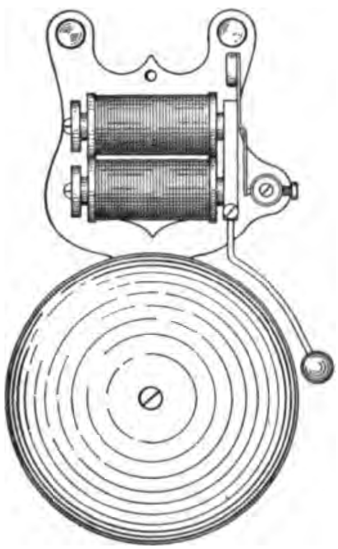


Fig. 10.

CIRCUITS.

The possible combinations of the various parts into complete circuits are so varied that it would be impossible to describe them all; in fact, almost every one is to a certain extent a special problem. It is, however, possible to give typical circuits the underlying principles of which can be applied successfully to any particular case.

Fig. 11 shows a bell circuit in its simplest form, in which P represents the push, B the bell, and C the battery; all connected in series. The circuit is normally open at P, and hence no current flows to exhaust the batteries. When P is pressed, the circuit, otherwise complete, is closed and current passes through the bell causing it to ring, as already explained. For instance, the push might be located beside the front door, the bell in the kitchen and the battery in the cellar; the location depending on the results desired and conditions to be met. The wire between P and C may, if necessary, be dispensed with and connection made to ground at G and G, as shown by the dotted lines.

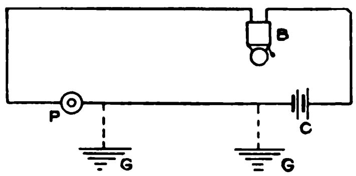


Fig. 11.

Fig. 12 shows an arrangement by means of which one bell B

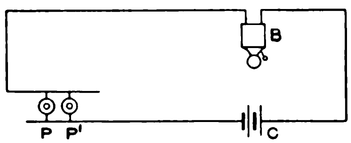


Fig. 12.

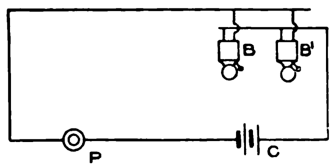


Fig. 13.

may be controlled by either of the pushes P or P'. This system may be extended to any number of pushes similarly connected.

A method for ringing two bells simultaneously from one push is shown in Fig. 13, where both bells B and B' will ring from push P. Bells, if connected in this manner, should have as nearly as possible the same resistance, otherwise the bell of lower resistance will take so much current that there will not be a sufficient amount left for the other. Also, the batteries must be of greater current capacity as the amount of current taken is, of course, doubled. This system can be extended to any number of bells connected in this way, up to the limit of capacity of the battery to ring them. Figs.

12 and 13 may be combined so that two or more bells may be rung from any one of two or more pushes.

In Fig. 14 is shown a scheme for ringing either bell, B or B′, from one push and one battery by means of the two-point switch

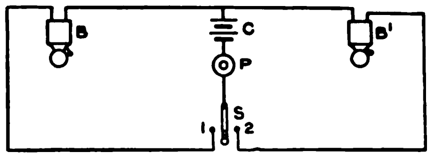


Fig. 14.

S. When the arm of the switch is on contact 1, the push will ring bell B, and when on contact 2 it will ring bell B′.

In Fig. 15 is shown a method of connecting bells in series so that B and B′ may be rung from P. If all the bells so connected were of the vibrating type, they would not work satisfactorily, as it would be impossible to time them so that the vibrations would keep step, hence only one bell should be of the vibrating type, and the others should have the circuit breakers short-circuited, the vibrating bell serving as interrupter for the whole series. Obviously this system requires a higher volt-

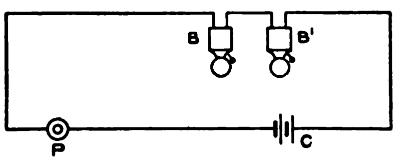
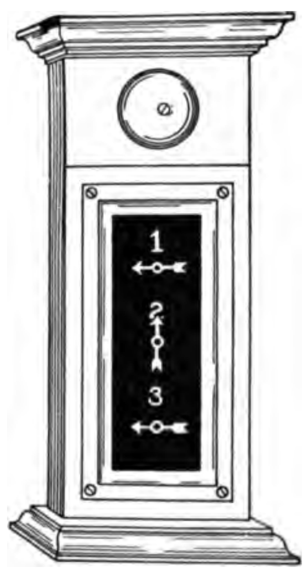


Fig. 15.

age than parallel connection, and the cells must be of sufficient E.M.F. to ring the bells satisfactorily. Several bells may be connected in this way, if desired, up to the limit of vol' ' the battery.



..r. 16.

Oftentimes a bell is to ... nt places. For instance, the bell i ... one of several floors, or the bell in the office of a hotel may be rung from any one of several different rooms. In this case it is necessary to have some device to indicate from which push the bell was rung. The annunciator furnishes this information very well. A three-station annunciator is shown in Fig. 16. The connections for an annunciator are shown in Fig. 17 where A represents the annunciator, B the bell, C the battery, and P^1, P^2, and P^3 the pushes. For instance, when P^1 is pressed, the current passes through the electromagnet controlling point 1 on the annunciator which causes

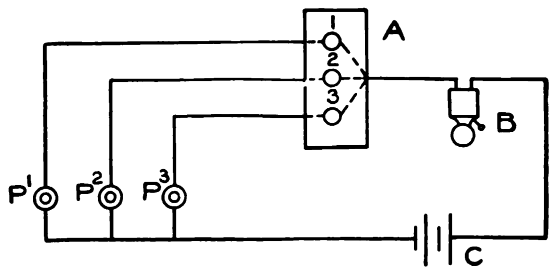
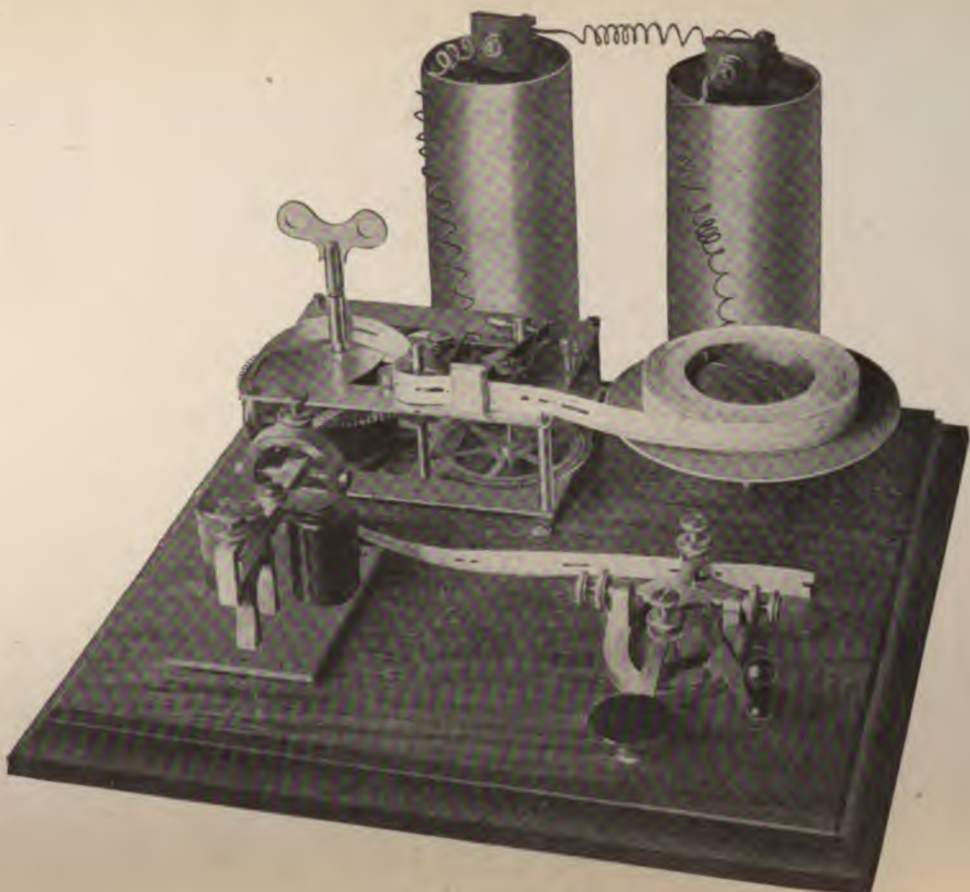


Fig. 17.

the arrow to be turned and at the same time the bell rings. After the attendant has noted the signal, the arrow is restored to its normal position by pressing a lever on the bottom of the annunciator box.

The electric burglar alarm furnishes a very efficient protection and is an application of the principles already described. The circuit, instead of being completed by a push, is completed by contacts placed on the doors or windows so that the opening of either will cause the bell to ring. The same device may be used on money-drawers, safes, etc.

In the case of the electric fire alarm, the signal may be given either automatically when the temperature reaches a certain degree, or pushes may be placed in convenient locations to be operated manually. The pushes should be protected by glass so that they will not be tampered with, it being necessary to break the glass to give the alarm.



Automatic Telegraph Transmitter

By means of the clockwork and perforated tape, this instrument reproduces the messages as accurately as an expert operator

THE ELECTRIC TELEGRAPH.

Apparatus and the Morse Code.

In order to get the beginner's point of view, it is taken for granted that the reader knows nothing of electricity or the practice of telegraphy. If there is a slight knowledge of either of these, so much the better; but as a starting-point, we will consider that altogether familiar use of the electric current in the ringing of a door-bell by pressing on a button. In so doing the new arrival "telegraphs" the fact to the household, and asks for admission, and those within respond to his message, although neither the one nor the other may know a dot from a dash. The simple combination of battery, wire and apparatus by which this action is carried on is as truly a telegraph circuit as is the longest in the land, and a glance at its elements will serve as a stepping stone to the more complex apparatus of the electric telegraph.

The different parts of the electric-bell device may be seen in their relation one to the other by reference to Fig. 1. In the center is the push-button P, pressing upon which brings the point of spring S into contact with the metal strip R. On one side is the cell A, with its two poles C and Z; on the other is the bell, with its electromagnet M, its armature hinged upon a spring K, carrying a hammer H, to strike the bell. Attached to the back of the armature is a spring, making contact at D with a back-stop T. These parts are so adjusted that when the armature is attracted by the magnet the contact at D is broken. Looking now at the diagram, if the wiring is traced from the point C back to the point Z, but one break will be found in the continuous contact of the wire with the different parts, and that is between the spring S and the strip R.

If, by means of the push-button, S is forced against R, the break is closed; the current speeds from the point C of the through the wire back to the point Z, charging the electromagnet M, which attracts armature-carrying hammer H. But by this movement the contact, and therefore the electric circuit, is broken at D, the current ceases, electromagnet M releases the hammer H; contact of the armature and back-stop at D is thus restored; magnet M is again charged, attracting the armature; the result being a vibration of the hammer, continued as long as spring S is kept in contact with R. The energy is derived from the cell, but the control of it lies in the push-button; and the effect of the making and breaking of the circuit at R is such as to appeal to the ear. By means not very different the same organ is addressed in teleg-

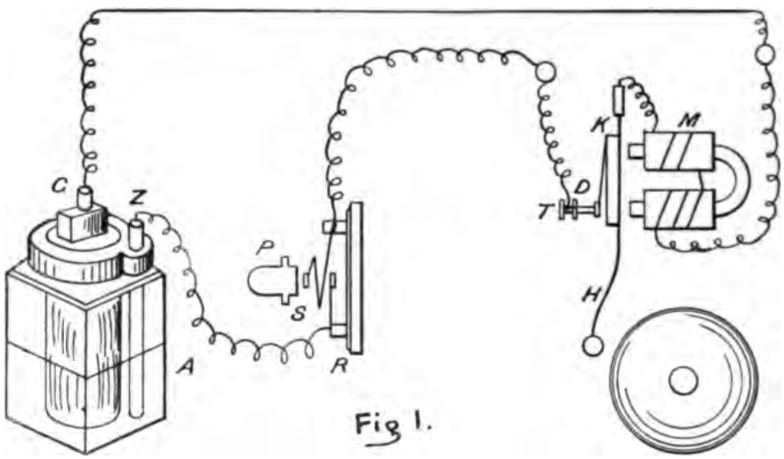


Fig. 1.

raphy; but the appeal is of a kind legible only to the expert. The bell device serves the further purpose of bringing the learner face to face, at the outset, with the fact of the inconceivable speed of the energy he is employing,— a feature which allies it to light in the velocity of its movement.

Having now gained a general idea of the action of a current in moving an armature, we will suppose that the reader, if in a city, has stepped into one of the many branch offices of a great telegraph company, or it may be into a town or village office of the same, and for the first time is taking notice of the outfit. In such an office there will be seen (secured to the wall) a small switchboard, but the interest centers on the table or desk, where there are usually three forms of apparatus, known as the relay, key and sounder, with the wires connecting the various parts. On the window-sill, or under the table, is the battery of one or two cells, for the operation of the sounder, shown in the Instruction Paper "Elements of Electricity." The uninitiated, listening to its clicks for the first time, naively expresses surprise that they "can make nothing of them." This set of apparatus, installed in thousands of small offices all over the continent, and duplicated many times in the large offices, is shown in outline in Fig. 2. The relay, described in "Elements of Electricity," is not heard at all; the main battery which operates it may be scores of miles away; the current from it has its path in the main, or air, line

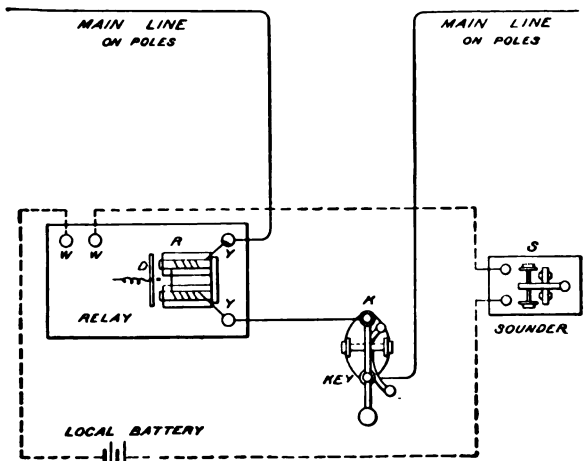


Fig. 2.

coming in from the pole in the street. Passing through the coils of the relays and the keys, it makes its exit through the office window, to resume its place on the poles which support it to the terminus of the line.

Examining Fig. 2 and comparing it with the bell-ringing device shown in Fig. 1, we find the cells of battery and the wiring common to both; the sounder corresponds to the bell proper; the key marked K answers to the push-button. The dotted lines in Fig. 2 represent the "local" circuit, and the cells are the "local" battery, so called because its action is confined to the place (Latin, *locus*) or station with which it is immediately connected. See the "Gravity Cell" in Elements of Electricity; the leads from the two poles being shown. If the *wherefore* of this pair of conductors and their connected parts is understood, the method of Morse telegraphy is within easy distance; and with the little light gained from the comparison of the electric bell with the telegraph circuits, we may take a step further in advance. For closer examination, therefore, this local circuit and its parts are reproduced on a larger scale in Fig. 3 and with more lettering. Each of the two cells of battery is surmounted by two projections called poles,—the terminal connections of two dissimilar substances, as copper and zinc, or zinc and carbon. The cell is explained in

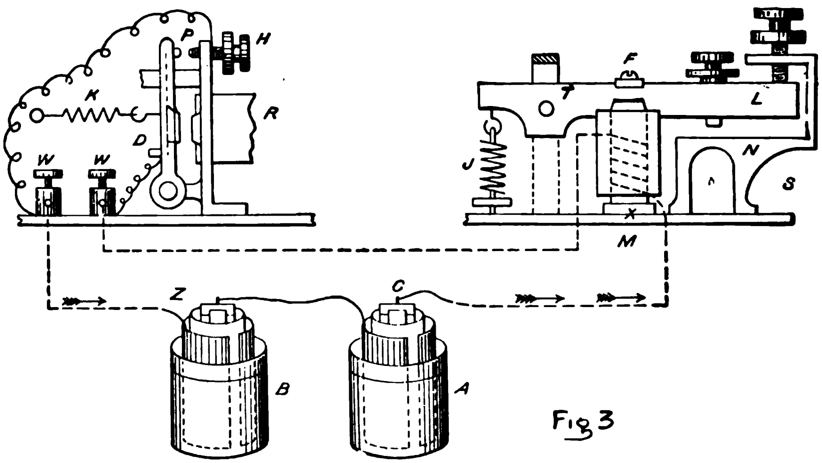


Fig 3

"Elements of Electricity;" all that need be noted now is that by outwardly joining up the cells so that the unlike substances are in metallic contact, a current is the result. First the carbon terminal or pole of one cell is connected to the zinc pole of the other; then from the carbon pole C of cell A runs a wire (dotted line) which can be traced through the coil of magnet M; thence to the armature D, and local points at P of the relay R back to the zinc pole Z of cell B. Of relay R only the moving parts are shown. The thumbscrews, wherever found, have connected to them wires from the different parts of the instrument, and are merely conveniences for making contact with the outside wiring.

Besides the battery of two cells and the conducting wires (dotted lines), the circuit, as already intimated, includes an electromagnet, consisting of a pair of upright coils (only one is shown), which, with the surmounting armature F and its adjacent parts, constitutes the sounder S. Each of the two upright coils of wire has a core of soft iron with a strip of iron X, joining them underneath. Close to the upper ends of the cores, but not touching, is a strip of soft iron F, called the armature, secured to a lever L, moving on trunnions T, at one end, its free end moving between two stops, the spring J serving for its adjustment. The movement of armature D of relay R is also limited by stops, and, tracing our dotted line circuit, we find a point P, where the circuit may be "broken" by withdrawing armature D from the front-stop H; just as in the case of the push-button, the circuit is "made" by pressure on the button, and "broken" by the withdrawal of it. In other words, in this armature D, with its front and back stop, and spring K, we have a telegraph key in a form the simplest and most easily understood, but not the most easily operated.

In a local circuit arranged as in Fig. 3, when armature D of relay R rests against its front-stop H, the current magnetizes the cores of electromagnet M of the sounder; armature F is strongly attracted thereto, making a sharp click as it strikes the down-stop N; a reverse or upward movement is determined by spring J if armature D of the relay is withdrawn from the front-stop, giving a sound less sharp than in the downward movement. The difference in sound between the front and back-stroke of the lever is something of which the learner must early take note, because the front is the marking stroke, or the one from which he reads, the back-stroke being unintelligible. In the former case (armature D against the front-stop), the circuit is said to be "made" or "closed;" in the latter it is "broken" or "open." Closed and open are the terms in general use among telegraphers. In the case of the electric bell, the push-button puts us in control of the energy which attracts the hammer to the gong. In the local arrangement we have been considering, the control of the sounder S lies in the armature D, whether moved by the finger, or in the usual way by the current.

In this dotted-line arrangement the wires are the carriers or conductors of an energy which has its source in chemical action in the cells. In the poverty of language it is said to "flow" or "run" within the cell from the zinc to the copper plate, or from zinc to carbon; and in the external portion (dotted line) from copper or carbon to zinc. Moving thus along the conducting wire and through the connected instruments it is called a current (Latin, *curro*, to run) and in doing so it is said to make a "circuit," which may vary in length from a few feet to hundreds of miles. Its velocity is such that wherever a fitting pathway is afforded, it seems not so much to flow as to be omnipresent. In a series of tests made in New York by the United States Coast Survey, two separate wires were obtained to San Francisco, where they were joined, or, as telegraphers say, "looped." To each of the New York ends of the wire, instruments were connected, and signals sent on the one wire returned on the other in a space of time just perceptible. The current had traversed the continent and back in a small fraction of a second,— a kind of movement which the words "flow" and "run" hardly describe.

It is the purpose of this description, to explain to the reader how it is that the signals heard on the sounder can have a meaning to the operator; how it is that the down and up movement of the lever of the key K, Fig. 3, can transmit intelligence to a distant station; then, briefly at first, but later on more completely, to instruct him in the method of operation, use and adjustment of each instrument in the set, so that in a reasonable period of time he will himself be able to send and receive the signals which before were unintelligible. At this point a number of questions may suggest themselves to the thoughtful student. Some of them, it may be, cannot be answered; others may belong to the theory of the art; but our present aim is entirely practical, the point being to beget in the student the ability to translate writing and speech into the "Morse" language; the consideration even of the main-line circuit is therefore deferred.

Summing up the examination of the local circuit there are

(1) The cells of battery as the source of energy,

(2) The conducting wires,

(3) The sounder S, consisting of an upright electromagnet having for an armature a movable lever; and

(4) A point P in the circuit at which, by a movement of the armature D of relay R, we can control at will the armature of sounder S.

In speaking of the relay R, Fig. 3, and its armature, the remark was made that in it we have a telegraph key in form the simplest and most easily understood, but not the most easily operated. Remove the dotted line wires from the thumbscrews of relay R and insert them, as in Fig. 4, in the terminals of a key K', described in "Elements of Electricity." We now have a "learner's outfit"—battery, key, sounder and connecting wires. Even with

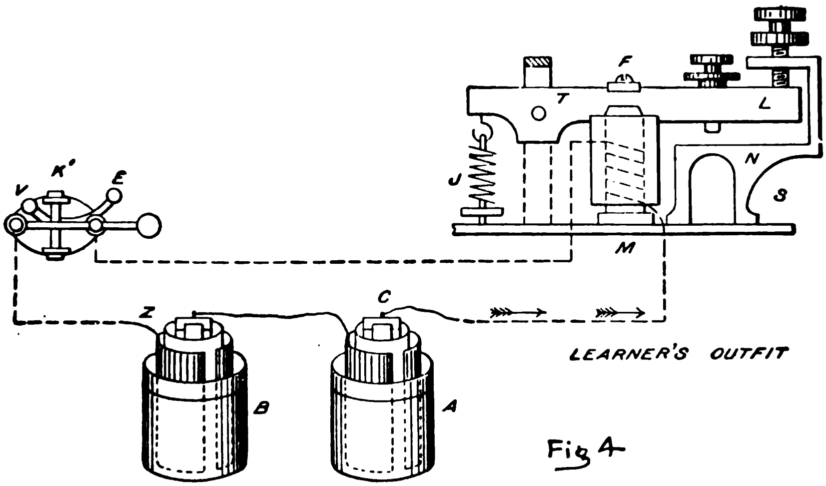


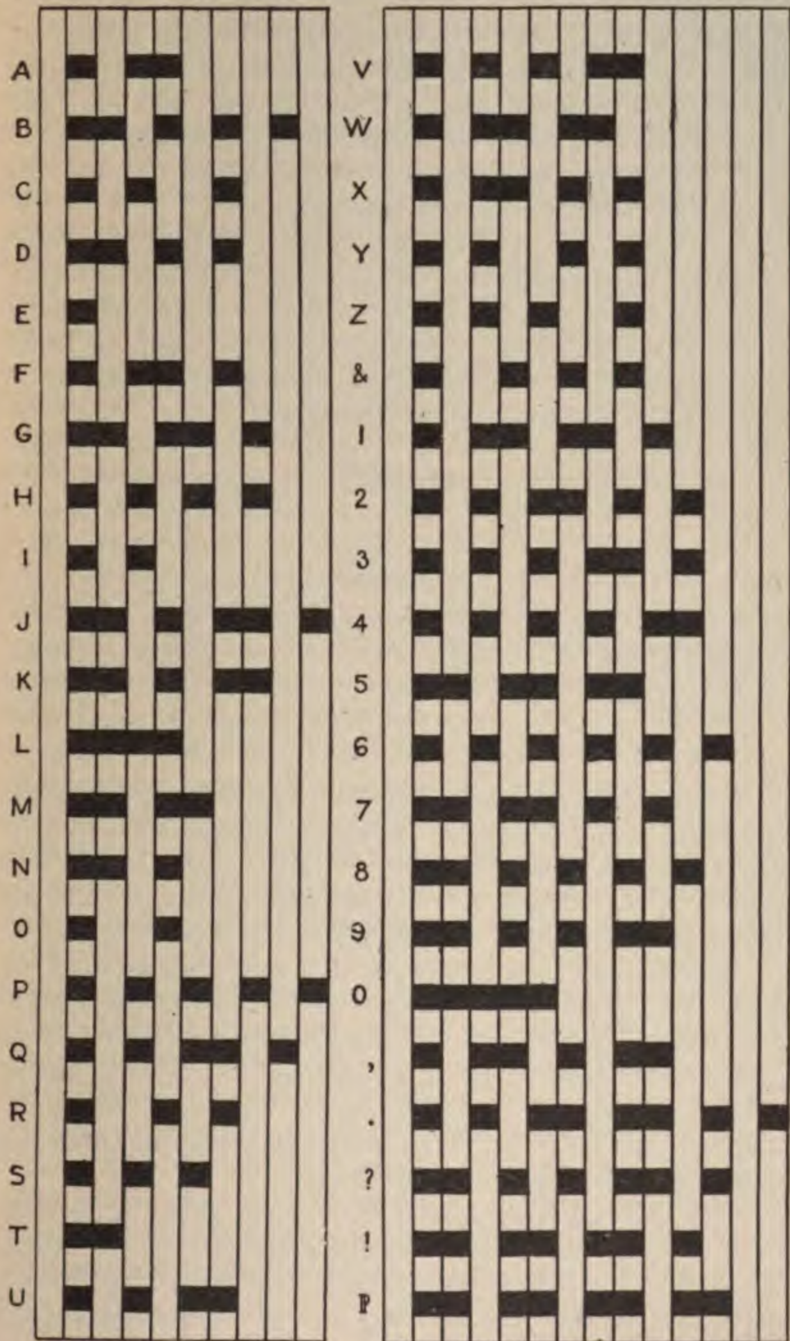
Fig 4

these, signalling to considerable distances can be carried on, and the medium for it is the Morse Telegraph Code, whose elements and their combinations to form letters are now to be taken up.

THE MORSE CODE.

It is taken for granted now that the student is provided with "a learner's outfit," comprising the apparatus shown in Fig. 4. The key K is provided with a curved arm E, hinged at V. By moving this to the right the key is opened. If, by tapping on the rubber knob of the lever, dots are made on the open key, it will be found that the armature of the sounder follows its movements. Having attained thus the control of an electromagnet, only a time element is needed in connection with the movements of the key to produce intelligible signals. In other words, if the open key is closed, by depressing the lever, now for a short, now for a longer time, or if the time between the moments of depression is varied, it is possible, by assigning the letters of the alphabet to different combinations of these movements, to make the instrument spell out the words of a language. To this end there was devised a system of dots, spaces and dashes, so arranged and combined that, singly or in groups, they are made to represent the different letters, figures and characters of the English language. If the learner (the key being open) hits the rubber knob a short, sharp blow with the finger, the sounder will give two clicks, one with the downward motion of the armature and one with the upward. The former has a sharp click, the latter a dull sound called the "back-stroke." The signal thus formed is called a dot, and its prolongation by a longer depression of the key is a dash; the down-stroke of the armature marks the beginning of a dot or dash, and the up or back stroke its end. In the movements for the production of the signals the time unit is the dot; by its duration all the dashes and spaces are measured. The single dot, produced as described, is the signal for the letter E, the letter in most frequent use having assigned to it an element the simplest and most easily formed. Prolong the dot to twice the time and we have the dash — the signal for the letter T; to four times the time, a longer dash, forming the letter L; to five times the time, and we have the signal for a cipher (0). To the hand the only difference between a dot and a dash is a longer depression of the key; to the ear the difference is in the interval between the down and up, or back-stroke of the armature. If the back-stroke were absent it would be impossible to distinguish E, T and L one from the other. It is not an uncommon thing for even the experienced operator to "get the back-stroke," in which case he dampens the up-stroke of the sounder with his finger until the ear catches the down-stroke again.

In the selection of the combinations which make up the code of signals, the principle, "the easy signal for the frequent letter," is observed throughout. The time value of the dot is constant, but the dash and space have each three different lengths. Two dots separated by a space of time approximately equal to a dot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represent the letter I, but two dots separated by a space equal in time to two dots represent O. The former is a mere interval, the latter is called the letter space; the word and sentence space are multiples of it — usually twice for the former and thrice for the latter. In naming the elements of the signal for the letter O, for example, they are read "dot, space and dot."

The entire scheme of the Morse Code, with its dots, spaces and dashes, their combinations and their relative time values computed according to the unit of time — the dot — and the letters, figures and characters they represent, is shown graphically in the accompanying chart, which the student must now, for a time at least, make his constant guide and reference.

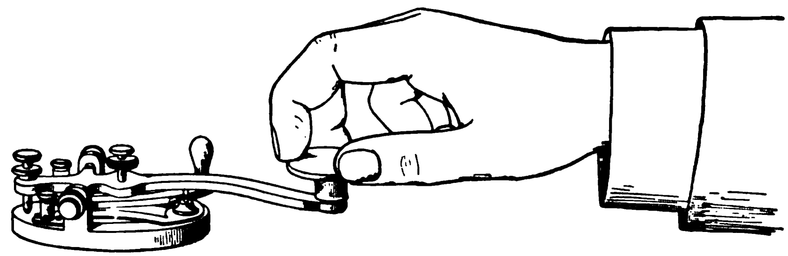


FIG. 5.

That we are able to present the alphabet in this preferred form is due to the courtesy of the D. Van Nostrand Company of New York, publishers of "Modern Practice of the Electric Telegraph" by F. L. Pope, to which manual, for details of nearly every topic in connection with telegraphy, the student is referred.

In this connection it may be of interest to state that the Morse Code, in the form in which it is now used, is the work of Alfred Vail of Morristown, N. J., and that in the selection of the signals for the different letters he was aided, so the story goes, by a chance visit to a printing-office, where he noticed that in the type cases the size of the different compartments was determined by the frequency of the use of the letter.

The attention of the learner having been called to the relative time values of the elements which go to make up the signals, he is now in a position to attempt for himself the making of them, and to take his first step as a sender. His instrument for this purpose is the key, with regard to which it has already been explained that it is merely a convenient device for the admission and non-admission of the current to the electromagnet of the sounder, according to a prearranged code. A suggestion as to the manner of holding the key can be gained from the cut (Fig. 5) given herewith. In it will be noticed the thumb pressing lightly upward against the rubber knob, the fore and second fingers curved, their tips slightly embedded in the knob, the wrist kept well above the line of the lever. This illustration, long familiar to telegraphers from its use in advertisements, and known among them as the "Catlin grip," is not intended for exact imitation. As in the case of handwriting, individual proclivities will assert themselves; but if the learner infers from it how to gain a firm command of the key, without cramping the fingers and forearm, he will have learned all that the text-book or a teacher can tell him.

At this stage some learners simply place the code chart before them and beginning at A, with its dot and dash, plod through the entire alphabet; then back and forth over the same ground, until they have obtained a certain mastery of the signals; and many good operators have learned in just this way. The writer has heard Mr. James D. Reid, "the father of telegraphers," relate that even on his way to assume his first position he re-enforced his limited practice by tapping out the alphabet with a pencil or a knife on the window of the railway coach or on the arm of a seat. But it seems more in keeping with up-to-date methods of instruction pursued in other branches to give to the exercises now to be entered upon a growing and developing character. With this end in view the different combinations of dot, space and dash are classified and arranged in six different modes—the signals for letters, figures, and common punctuation points only being considered at present. A mere glance at the chart will indicate to the eye the differences already noted in the lengths of the dashes; the letter L is represented by a dash twice as long as T; and the signal for a cipher is a dash two and a half times as long as T. It is as well for the beginner to observe these relative lengths; but in actual work the dashes undergo some shortening without danger of error.

1. Dot only, . E .. I ... S .... H ..... P
2. Dash only, — T—— L——— cipher — — M — — — 5
— — — — paragraph
3. Dot preceding the dash, . — A .. — U ... — V .... — 4
. — — W
4. Dot following the dash, — . N — .. D — ... B — — .. 7
— .... 8 — — . G — — — . exclamation
5. A combination of (3) and (4) . — . F — . — . J — . - K
.. — . Q . — .. X . — — . 1 .. — .. 2 ... — . 3
— .. — 9 . — . — comma .. — — .. period
— .. — . interrogation
6. Dot and space, .. . C . . O . .. R .. .. Y ... . Z . ... &

The method to be followed by the student looks to the repetition of the signals for these letters and characters, first in direct order as given, and then in reverse. In this way his work is graduated, and his ear will soon become accustomed to the difference as the elements increase or decrease. Especially is this true in regard to the first mode; and in connection with the second it is to be noticed that while the dot always has the same time value, the dash, as already stated, has three different values, as indicated by the length of the lines for T, L, and cipher in the chart. The T dash repeated gives us the letter M; used thrice, the Fig. 5, and four times, the signal for a paragraph.

The third mode includes those letters and characters in which a dash or dashes is preceded by a dot or dots. They represent the letters A, U, V, W, Fig. 4. And for mode four we have a reversal of the elements in the preceding one; dot follows dash, and signals are thus composed for letters N, D, B, G, Figs. 7 and 8, and the exclamation point.

In the fifth mode the order is miscellaneous; and the more complex and difficult signals thus obtained, have assigned to them the letters least often used. They are F, J, K, Q, X, figures 1, 2, 3, 9, the comma, the period and interrogation. Last come the so-called spaced letters — of all the signals, requiring in their formation and grouping the most care. They are C, O, R, Y, Z, &; and their persistent repetition, both singly and in combinations of short words, is enjoined upon the student.

The telegraphic equivalents of all the letters, figures and more common punctuation marks having been given, attention is next called to groups of letters having signals somewhat similar.

For the letters and characters in these groups the student can find for himself the signals in the code card. He can, by inspection, determine for himself the exact difference in each case, as, for instance, in the first of the following groups A differs from I by the change of a dot into a dash.
1. I, A, S, U, H, V.
2. A, F, X, comma, W, 1.
3. U, Q, 2, period, 3.
4. K, J, 9, ?, G, 7, !

The signals for these letters and characters having by repetition become familiar to the ear, the combination of letters into words, may next be taken up. In the course of the plodding thus far pursued, the learner may begin to think that the slow analysis by the brain and the mental noting of every signal must be an irksome task. But he will find as he advances that by degrees the analysis becomes mechanical; certain sounds come to mean letters, groups of sounds, words. The real alphabet of the expert telegrapher is largely one of words; to him the clicking of the sounder is a language, and its interpretation as easy as that of speech. It is therefore with the combination of letters into words that we have now to do. And in pursuance of the progressive plan the exercises revert at this point to the order in which the signals were classified; that is, words are made up first of dot letters, then of dash letters, and so on.

1. Of the dot letters can be formed the words is, she, ship, hips, his, pies, sip, pipe, sheep.

As it is not possible to furnish many words made up exclusively of the letters in each group, single letters from other groups are here and there borrowed to make up some exercise words; as for instance, in the old-time favorites with learners, pippin and Mississippi, in which N and M belong to another group.

Exercises in words containing dot letters:

Dishes, dispel, high, dipped, Spanish, spite, shipshape, diminish, dishevel, phase, dapple, hiss, hissing.

2. Dash letters: Met, tell, till, time, mill, pellmell, metal, limit, telltale, mamma, mammal, minimum, little, time, tittle, tattle, emit, timid, multiple, multitude, dimmed, mallet, skillet, skimmed.

3. Dot before dash letters: Awe, awful, awl, law, mauve, value, valve, wave, Eva, vault, view, lava, vamp, haul, pawl, squaw.

4. Dash before dot letters: Bend, bidden, gilded, laden, dined, begemmed, dunned, dabble, nab, ban, Denbigh, Big Indian, quagga.

5. Combination of (3) and (4): Julep, jungle, junk, Fiji king, fast bind, fast find, quit, equal, quaff, quake, exit, exist, ex-queen, exquisite, exhaust, skiff, piquant. Affix a k to kin and it is kink, bequeath, quaint, mujik, Ajax, Xanthine, jejune, jujube, keg, fix.

Thus far no words containing a spaced letter have been admitted. The hand and ear are thus first accustomed to the signals whose elements are separated by a uniform interval of time. By reference to the code card the learner will notice the difference in the spacing between s and c, i and o, s and r, h and y, h and z. The addition of the spaced letters makes the alphabet complete, and a number of excellent practice words omitted heretofore are now available.

6. Spaced letters: Or, err, to err is human, errant, corner, Corcyra, correct the error, eczema, corollary, co-operate, Corcoran & Co., coon, raccoon, circus, circle, cycle, bicycle, current, currant, cracker, firecracker, chronicle, coccyx, buzzard, zyrcon, correlate, physics, phantasmagoria, rhododendron, corrupt, cohesion, corduroy, road, dory, hippopotamus. There is no royal road to learning. The voice said Cry. What shall I cry? According to Sinbad the sailor, the roc's egg was enormous in size. Llewellyn, sassafras, crown, point, parallelogram, oyster, eyelet, icicle. ice-cream, puzzle, bamboozle, binocular, verdict, door, category, oracle, rollicking, moored, marooned, pirate, gyratory, circumstance, circumgyratory, paraphernalia, jiffy, effigy, equinox, quiz, Quixotic. Peter Piper's peacock picked a peck of pepper out of a pewter platter.

A few easy messages of ordinary commercial form are here introduced, attention being called to the fact that the destination occupies a line by itself. This is done so that the distributors in the larger offices can catch the "place to" at a glance.

116 B.	R N	M B	11 Paid.

RECEIVED at the . . . BUILDING, . . Broadway, N. Y. July 12, 1902.

Dated Bar Harbor, Me., 12.

To Theo. Faulkner,

Jenkintown, Pa.,

Can give same room as last year—twenty-eight dollars. Answer.

(Sig.) J. S. LYMAN.

17 Ki.	M O	N D	7 Paid.

RECEIVED at the . . . BUILDING, . . Broadway, N. Y. July 12, 1902.

Dated Kingston Depot, N. Y., 12.

To Mexican Gulf Agricultural Co.,

Dallas, Tex.

Arrive there Monday morning, 8.55.

(Sig.) ALLEN.

184	U D	B	20 D. H.

RECEIVED at the . . . BUILDING, . . Broadway, N. Y. July 12, 1902.

Dated Mamaroneck, N. Y., 12.

To G. F. Harriman,

Pullman Co.,

Detroit, Mich.,

Empire Coupler Co. shipped car load of couplers to-day in D. L. & W. car 58,031.

(Sig.) H. M. WYATT.

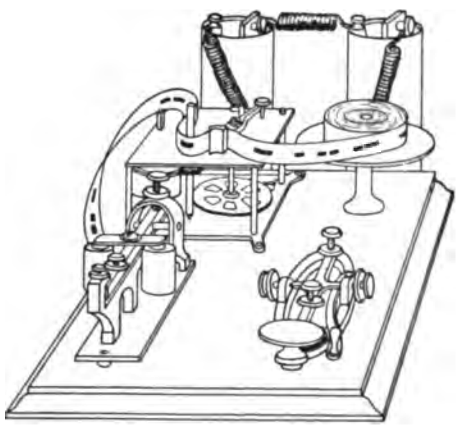
In the top line the first space contains the number, and generally the call of the sending station; the second and third spaces, the signals of the sending and receiving operators; the fourth, the check. In practice the signature is also on a line by itself.

By attention to the response of the sounder as he forms the letters on the key, the learner has now to some extent familiarized himself with the *sound* of the signals as he translates their form, as printed in the code card, into the key movements necessary to produce the dot, space, and dash. Reading the signals as they are embossed on paper by a "register," except for some special uses, has become obsolete in telegraphy, so that it is with the *sound* that the learner has entirely to deal; and the signals from which he must copy are those of a hand not his own on a distant key. In this, as in handwriting, there are individual differences; and the query whether operators can recognize one another over the wire by their "Morse" can be answered affirmatively. Since much depends on the initial practice in the formation of his style, the learner should, if possible, at the outset take a few lessons from an operator. That these remarks are practical and not perfunctory, the writer has personal knowledge at the present time of the contemplated removal of operators from some important circuits because of their defective sending. To aid in the formation of a correct style the signals have been presented in a graded form, beginning with the dot, which is the unit of time, passing on to the dash, then to the various combinations of dots and dashes, and lastly of dots and spaces; all with a view to their reproduction in words, phrases and sentences.

The Automatic Sounder Method. It was intimated that, for beginners, it was advisable to observe closely the relative length of the signals as indicated by the chart, especially the dashes, and that, on this account, it would be well for them to take a few lessons from an operator at the outset. In order, however, to do away with the necessity for this, there is brought to their notice a device of Mr. R. W. Elam of Valparaiso, Indiana, for the reproduction of signals the same in effect as if sent by hand, thus supplying in a great measure the guidance of an experienced teacher.

The apparatus is constructed by the National Automatic Transmitter Company and is furnished to students by the American School of Correspondence. In addition to the apparatus itself, the student is supplied with a set of records representing the letters and characters in the Morse code; the apparatus reproduces them in such a manner that, in the formative period, the learner may accustom his ear to the signals as made by an expert. These records are exact reproductions of the characters as made by hand; having been transmitted to the recording perforator by an expert operator through the use of an ordinary telegraph key. So natural are the messages thus reproduced that the individuality of the sender's "wire-writing" can be detected.

The Apparatus. In the form furnished to students it is mounted on a base, 11½ by 12 inches, made of quarter-sawed oak, finely finished; and comprises a learner's outfit consisting of a key, sounder and battery such as have been previously described; with clock-work and circuit-breaking mechanism through which moves a strip of perforated tape. To the axle of the clock-work, where it projects through the frame, is affixed a friction wheel which imparts its motion to the tape. Between the wheel and the tape holder is a curved pad against which the tape is pressed by an arm pivoted nearer to the end next the pad which we will call A; the other end we will call B. A slight deflection, therefore, of end A is quite marked at end B; the movement of the latter is limited by a stop similar to the armature of a relay. Like the relay also, at its end B the pivoted arm and the stop make connection with the poles of a local battery, so that when contact is made between the arm and the stop, the circuit through the sounder is closed; when the contact is broken the sounder is open.



AUTO-ALPHABET INSTRUMENT.

The slight movement of the arm needed to operate the sounder is effected by running the perforated tape between the end A of the arm, and the curved pad; when the end A is against the paper the sounder is open; it is closed whenever end A drops into an opening.

In the tape the student will readily see that the smallest openings represent the dots of the Morse code; the larger ones the dashes of different lengths.

Releasing the brake with which the mechanism is provided, the paper moves forward, imparting to the pivoted arm a series of movements which the sounder translates to the ear; the perforated tape acts as an automatic circuit breaker, producing the signals on the sounder precisely as the key does, and with greater accuracy as to relative units of time. In effect the signals are being sent by hand; to have them at his command is a great advantage to the beginner, some of whose tendencies to error are set forth in a later paragraph.

The course comprises a series of records capable of reproducing the work of an expert as effectively as if he were listening to the actual working of a wire. Another advantage lies in the fact that the speed with which the messages are sent can be varied over a wide range so that the student can use a slow speed when first taking up the work and, as he becomes more expert, can increase this to keep pace with his advance. The instrument can also be made to repeat any given message as many times as the student desires.

To insure good results the local points, where the arm touches the front stop, should be kept clean; and it may be necessary at times to pass a fine file lightly between them. The clockwork needs no attention beyond the winding up, and an occasional oiling.

The parts of the learner's outfit have been described elsewhere, and in such a manner as should make clear how closely it resembles the local circuit of the regular Morse Line. In placing the tape, see that the signals read in the direction away from the marking arm. The speed should be slow at first; the learner should note the perforations and mentally name the letters and characters as they pass toward the arm, so that when the sounder records them, the ear will associate the sounds with the signals.

A number of these strips are furnished the student; but the one with which he should first familiarize himself is that in which the exercises follow the course indicated below; the words are grouped according to the six modes just indicated; they are made up first of dot letters, then of dash letters, and so on. In pursuance of this plan the particular tape in question is perforated to render the following:

Is she ship his pies sip pipe sheep.

The learner may, if he chooses, stop the movement at this point, and, going back to the word "is," reproduce the series any desired number of times. Following upon the word "sheep" the sounder will reproduce the following words composed for the most part of dots:

Dishes dispel high dipped Spanish spite shipshape diminish pippin Mississippi dishevel phase dapple hiss hissing

Following upon this the sounder will render the exercise words in paragraph 2: Met tell till time mill pellmell metal limit telltale mamma mammal minimum little time tittle tattle emit timid multiple multitude dimmed mallet skillet skimmed; paragraph 3: Awe awful awl law mauve value valve wave Eva vault view lava vamp haul pawl squaw, and so on through paragraphs 4 and 5.

Paragraph 6: Or err to err is human errant corner Corcyra correct the error eczema corollary co-operate Corcoran & Co. coon racoon circus circle cycle bicycle current currant cracker firecracker chronicle coccyx buzzard zyrcon correlate physics phantasmagoria rhododendron corrupt cohesion corduroy road dory hippopotamus. There is no royal road to learning.

Some Faults of the Beginner. The learner may now, with key in hand held in the manner indicated, traverse once more the ground over which he has gone; but this time, he goes along with the notations of certain incorrect tendencies and faults which mark the beginner's work. He can take up those letters whose elements are simple dots, viz., e, i, s, h, p, and practice on the words already furnished, or upon combinations of his own. He will be interested at this point, to know that some experienced operators cannot make the five dots which form the letter P, and that many more cannot make the six dots of the figure 6. If the learner would avoid the "seven," "eight," and "ten-dot" habit, he should start in slowly, giving definite values to his dots, making the intervals uniform, until some approach to precision is reached. Avoid shortening or clipping the final dot, and make sure by actual count at first that the correct number for each character is made.

Following upon the dot mode are the four short dash characters for the letters T and M, the figure 5, the paragraph; and the elongated dash characters for L and cipher. Here, again, a tendency to shorten or lengthen the terminal dash and to space unduly the successive dashes should be guarded against. It is well to observe at first the relative time value of the dashes, but in practice the cipher and L dashes approach one another very closely without inconvenience. Occurring alone or among other letters the long dash is translated as L; among figures it is read as cipher. As between T and L, the usual inclination among learners is to make the T too long and the L too short.

In the next mode, in which the dot or dots occur first, the tendency is to separate too much the dot and dash elements. The interval between them should be appreciable to the ear, but no more. The places of these elements are reversed in the fourth mode to form the letters N, D, B, the figures 7 and 8, and the exclamation point. The first two should offer no difficulty, but B, 7 and 8 are troublesome, the tendency being to add in each case to the prescribed number of dots. There are operators who make the figure 8 for B, and a dash and five dots for 8; but no one careful of his work allows himself to fall into this habit.

Then there is that combination of the dot and dash elements which gives us the letters F, J, K, Q, A, figures 1, 2, 3, 9, the comma and the period. Of these, J and K are usually considered the most difficult, the tendency being to make a double N of the J, and the dashes of unequal length in both. The last mode brings us to the test of a good sender, in the deftness with which he makes the spaced letters unmistakable to the receiver; and he does this by such slight modifications of the space as the exigencies of the different combinations call for. The space in these characters is a prolonging of the necessary interval between the elements, and it should be just enough in excess of it to make the letters O, C, Z, for instance, distinguishable from I, S and H; and the spaces between the successive letters of a group of spaced letters should be slightly greater than the ordinary letter space. Some unfamiliar words, such as coerce, offer such a succession of spaced letters that it is usual for careful operators to repeat the word thus: coerce? coerce — the interrogation point implying "Did you get it correctly?" It should hardly be necessary to warn the learner against the stereotyped mistake of beginners — that of going over a great deal of ground and doing nothing thoroughly. The real progress lies in correct work as one goes along, and accuracy at first in the formation of the signals will lay the foundation for safe and rapid work. The student has already been apprised, by means of three examples, what the ordinary message form is; but something more than "a learner's outfit" is needed for the exchange of messages. The point has now been reached for the consideration of the main-line circuit, to which the electric bell and the local circuit have formed a kind of introduction.

THE MAIN-LINE CIRCUIT.

As compared with the local circuit, or learner's outfit, no new

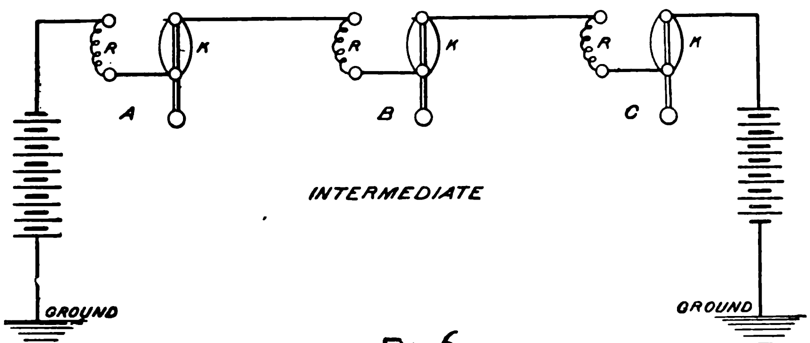


Fig 6.

principle is involved in its operation. The local circuit, with its few yards of connecting wire, has all the essential features of the longest Morse line working single; the differences are merely those of adaptation to new conditions.

First to be made clear is the difference between a metallic and a ground circuit, as exemplified in a local and a main-line; and the location of the latter battery with respect to the the main line. Reverting now to the battery in the local circuit (Figs. 3 and 4), it will be noticed that, where the sides of the cells adjoin, the two unlike poles are connected by a short piece of wire. This, with the longer piece passing through the instruments and connecting the other poles, forms what is called a metallic circuit, because the entire path of the current is of metal. If the short piece of wire between the cells be broken in two and both ends sunk in the damp earth, the circuit will be found intact

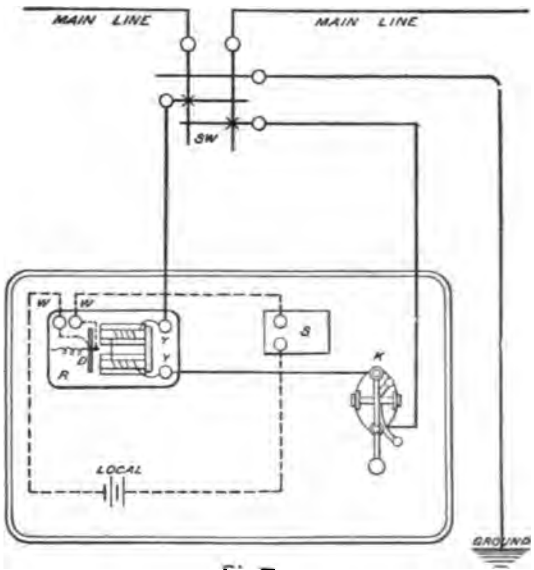


Fig 7.

as before, the current finding a path through the ground; and instead of a metallic we have what is called a "ground," or (in England) "earth" circuit. At this stage we must content ourselves with the fact that the earth acts as a return wire; the reason for it belongs to the theory of electricity. The main line is a ground circuit, not a metallic one; and the location of the main batteries relatively to the rest of the circuit is made plain in Fig. 6. In it are shown two terminal stations, each with main battery, relay R and key K; and between them is an intermediate station. The circuit here shown may be hundreds of miles in length. The cells at each terminal are usually about 150 in number; at terminal A in the drawing the copper pole is grounded, and the zinc goes to the main line; at terminal C these conditions are reversed.

Between the terminals there may be a score or more of intermediate stations, of which only one (B) is represented in the drawing; and as its position in regard to the main line is made clear, the details of an intermediate station, hitherto passed over, are now to be described. For this purpose attention is called to Fig. 7, in which is shown, more in detail than in Fig. 2, an intermediate or way-station, with its main lines appearing at the top, its switchboard, relay, key, sounder and local circuit (dotted line) all complete. As compared with the "learner's out-

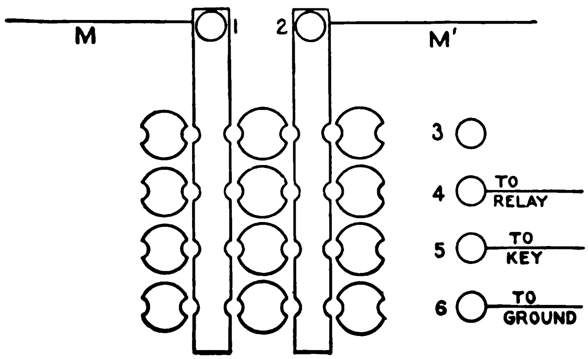


Fig. 8

fit" the additional parts are the relay and switchboard Sw. The wires marked "main line" are identical with those extending in either direction from station B in Fig. 6. In connection with relay R, Fig. 7, the dotted lines which are seen in Fig. 4 inserted in a key are replaced in the thumbscrews of the relay; and the armature and front stop of the relay are again a part of the local circuit. The coils of the relay cores, of which the thumbscrews Y Y are the terminals, form part of the main circuit, just as the coils of the sounder in Figs. 3 and 4 form part of the local circuit; but in the construction of the relay as compared with the sounder, some new features may be noted. The latter instrument is operated by a battery close at hand, for which only a few yards of wire are required; but the relay is only one of a number of similar instruments operated by a battery or batteries through hundreds of miles of wire — a problem in which the matter of economy is also a factor. The cells of battery at each main line terminal was given as 150; but even with this number a meter inserted in the main line of an ordinary telegraph circuit would show a very feeble current. If an ordinary sounder were "cut in" on such a line, there would be no response of the armature to the opening and closing of the circuit, for the reason that the winding of its coils is not suited to the conditions. But in the relay, in order to obtain a sufficient amount of magnetism, the coils are wound with many more turns of much smaller wire. To make room for the additional turns, the soft iron cores are made longer; because of their length they are placed parallel with the base instead of standing up, and the other parts are made to correspond. The winding of the relay coils has its terminals in thumbscrews Y Y, Fig. 7; and if from one of them the main line wire is detached and tapped firmly against the thumbscrew, not only will armature D of relay R respond to the action, but all the relays on the line, be they two or twenty, open and close in unison with the non-contact or contact of the detached wire with the thumbscrew. Then because the movement of the armature of the relay opens and closes the local circuit of each and every relay along the line, the sounder in each local circuit moves in unison with the home relay — a result brought about by merely tapping the thumbscrew of the home relay with the main line wire temporarily detached from it. But the detaching and tapping method has been resorted to only to emphasize for the learner the essential features of a telegraph circuit. In practice the tapping is done much more conveniently with the key, with whose use the learner is presumed to be already somewhat familiar. And as he either has one in his possession, or the use of one, he can examine its construction for himself, so that a description of it here is unnecessary. With the key in the main line circuit to do the work done by detaching the wire from the relay, it is plain that all the instruments in the circuit can be controlled by the movements of the key; when the operator opens the key by moving the curved arm from under the spur (see Fig. 4), all the relays instantly open; when he depresses the lever they all as instantly close. This result is possible because of the velocity of the current — the time consumed in traversing five hundred miles being inappreciable. It should now be plain to the learner how it is that the control of a key at any point in the circuit enables him to exchange signals with a distant station; and, in doing so, he "telegraphs" or, as the word means, writes at a distance; for telegraphy is distance writing, just as telephony is distance speaking.

Mention may be made here of a new form of key which in its construction and operation is a radical departure from the form hitherto in general use. The handling of the ordinary key for any length of time is a serious tax on the muscles of the forearm, resulting in some instances in an ailment known as "telegrapher's cramp." The new form of key was devised with a view to relieve the strain on the forearm by a form of lever which is not only initially different from the ordinary one, but admits of being instantly shifted into various positions, as the sender feels the need.

THE SWITCHBOARD.

One part of the apparatus of a way-station remains to be described; it is called the "switchboard," and is usually secured to the wall over the operating desk. It enables the operator to change the arrangement of the wires leading from the desk with respect to the main line, and to the ground. It is simply a board of well-seasoned wood, fitted in front with metal strips running vertically and terminating in thumbscrews; horizontally across the board are rows of small circles of metal, called discs, whose stems pass through the board, at whose back each row is connected together with a wire terminating in thumbscrews in front and at one side of the board. The strips and discs are so constructed with reference to each other, that connection can be made between them by a metal peg having a short handle of rubber. The switchboard is seen in position in Fig. 7, but is reproduced on a larger scale in Fig. 8. The different rows of discs (each row having a connecting wire at the back) have their terminals in the thumbscrews 3, 4, 5, 6, of which 4 and 5 make direct connection with the relay and key, and 6 makes connection with the ground. Suppose the way-station to be between New York and Albany;

let M represent the main line from New York, making connecti with the thumbscrew 1; and M' the wire to Albany connecti with 2. Look briefly at a few changes in the connections th can be made by means of two metal pegs. Suppose each of t discs in a given row to be numbered as shown on the right of th row. Connect with pegs 1, 3 and 3, 2. In this case the curre would simply pass from bar to bar across the middle disc 3 wit out affecting the instruments at all; and in this position of t pegs they are said to be "cut out." Move the peg in 1, 3 to 1, and the main line circuit is open because there is connection on between discs of the same row. Move the peg in 3, 2 to 5, 2 an the current has to pass through key and relay in going from o upright bar to the other, and the apparatus is said to be "cut in The drawing represents the switchboard in its simplest form, an the operations indicated are the most ordinary; but if the learn will bear in mind that the discs are connected with each oth only in straight lines across the board, he can trace out for himse other peg connections of discs and bars and the changes the bring about in the circuit. For instance, discs 6 all connect wit the ground. Remove the peg from 1, 4 to 1, 6 and from 5, 2 t 6, 2; the wire from both directions is now grounded, with th result that there are now two independent circuits—one in eac direction from the way-station whose operator could now wor with either New York or Albany, but the stations named woul be cut off one from the other. Restore the pegs to their origin position in 1, 3 and 3, 2, and the terminal stations can work wit each other, but the way-station is once more "cut out." This the position in which the pegs should be placed when the operat leaves the office, or during a thunderstorm. But for the latt incident there is generally arranged a "cut out" outside the offic Many intermediate stations have more than one wire and switc board to correspond, and it would be possible to fill pages wit the combinations that might be effected; but sufficient explanatio has been given to indicate the method which, when once unde stood, can easily be extended and applied to suit larger needs.

In the care and adjustment of his instruments, the operat should see that the local points of his relay and the points of h key are clean; he should be on his guard to see that the armatu of his relay or sounder does not hit upon the soft iron of the cores. A good way to assure himself of this is to pass a piece of paper at times between the armature and the core. Instructions in the care of the local battery are now in order; but they differ with the kind of battery used, and are usually furnished in the book of rules of each company.

The purpose up to this point has been to give the reader an idea of the apparatus employed in telegraphy. It has been emphasized thus far that the essential features of the local circuit, viz., battery, electro-magnets, and connecting wires, are all reproduced in the main circuit, the differences being only those of adaptation to new conditions.

With this statement a reversion is now made to the practical — to the matter of the exchange of messages, of which some examples of the ordinary form have already been given. The greater part of the business handled by the commercial companies is of the kind exhibited; but the work of the operator would be easy if it consisted in exchanging only such messages as the samples. In addition to the ordinary form, there are those known among telegraphers by the following terms: Wire, service, forwarded message, repeated back, government, grain, transfer, cipher, number group, circular, C. N. D. (Commercial News Department), marine, and railway D. H. Then there is the press service, making use, in some cases, of fixed forms for a baseball score, golf score, and the like. Of ordinary press matter the volume on certain occasions, such as a presidential convention, is great. At the present time much of the press matter is handled on wires leased from the telegraph companies by the press associations, and their carrying capacity is increased by the use of a code which enables an operator to transmit as fast as an expert typewriter, at his highest speed, can copy. Of code telegraphy, some details will be given later on. In addition to all these the art has been specialized by railway companies in the movement of their trains and traffic, also by brokers and large commercial houses, to such an extent that even an expert operator must serve an apprenticeship in order to fit himself for the rapid work in these specialized forms.

Of the different kinds of messages just enumerated, the first two designations are self-explanatory, the former having to do with the assignment, arrangement, and cross-connection of wires; the latter with the forwarding, re-addressing, and deliverv of telegrams. Service messages have to do with the movement of the despatch from the customer to the hands of the party addressed, and, if errors have been made, with their correction.

The following are examples of this form of message:

Marietta Pa ofs.

Give full address Oswald Denberg. We fail to locate your msg date signed National El. Co. S. Y. S. (sig) Munn, New York.

The use of abbreviations will be noted; and for some constantly recurring phrases, such as "see your service," only the initials are used. "Give better address" is similarly represented by G. B. A.

Munn, N. Y.

Pls D. W. C. from original yours today Carnegie Steel Co. signed Union National Bank, A. L. Dignam Cashier. Same reaches us dated Waterbury Conn.; Carnegie say think should be dated Watertown N. Y. Advise my care.

(sig) Phila., Pa.

In this case a "duplicate with care" is requested.

An extra-date message is one that has been received by mail at, say, Albany office; or, having come over another line, has been handed in to be sent forward, and takes this form:

116A Bn Mo 15 Paid

Berlin, N. Y. Oct. 26, via Albany Oct. 26

Adam Brown,

Bridgeport, Conn.

Have been unexpectedly detained. Meet me next Monday at ten. H. Brosnan.

In this case the five words "Berlin N. Y. Oct. 26" are added in and charged for as part of the message. It is customary when the party to whom a message is addressed has left town, to forward it to a given address, in which case the forwarding station, with the word *via*, appears in the date, and the originating station and date are charged for, the same as in the example just given.

Occasionally the sender of a message, to insure its correctness, requests a repetition, in which case the words "repeat back" are inserted in the check and included in the count. For such repetition a charge of a rate and a half is made. A "night message" does not differ in form from the examples of paid messages already given, except that it is always copied on a blank printed in red ink, and in the check is inserted the word "night," which is not counted. In all collect messages, whether day or night, the word "collect" is counted as if part of the body of the message.

Government messages are exchanged between the officials of the United States government and its employees, and differ from the ordinary form in that the address and signature are counted as part of the body of the message, thus:

197W Kn Mg 28 Paid Gov't
Washington, D. C. June 24
Col. H. K. Ames
Memphis, Tenn.

Forward to New Orleans all the tents and rations you can spare in aid of the flooded district.

(sig) E. M. Harrison,
Commissary General.

The text or body of this message contains only seventeen words; but the count of every word in the address and signature makes the check twenty-eight.

A prominent feature of commercial telegraphy at the present day is the facilities provided for the quick interchange of messages between Produce, Stock, and Cotton Exchanges in cities remote from each other, the circuit arrangements being such that the members of these bodies can carry on their trading with a celerity and correctness that leave little to be improved upon. Many of these traders have their own private wires; but the greater part of this class of business is carried on by the New York Produce Exchange with the different grain centres, such as Buffalo, Toledo, Detroit, Chicago, Duluth. In the forms of messages hitherto given each message is preceded by its number, the signals of the sending and receiving operators, and the check. In the exchange of grain orders all this, with the exception of the number, is dispensed with. To show the difference in usage between the ordinary and the exchange form, a message is given in both:

B123 Da Mo 7 Paid

Ex Chicago, May 18

J. C. Ladenberg,

New York.

Sell five July corn at sixty half.

(sig) M. J. ALLEN.

In practice this would be transmitted in abbreviated form, thus:

B186 7 Pd.

Ex. J. C. L. Sell etc. (sig) M. J. A.

Such work, of course, calls for experience on the part of the operator and great familiarity with the names of his patrons; these being granted, the volume of business that can be handled during exchange hours is large.

There has been evolved in connection with the telegraph service a great convenience to the business community in the order by wire to pay to one party money deposited by another — a transaction possible between cities on opposite sides of the continent. The instrument of this exchange is a message called a "transfer," of which the following is the common form:

B171 Dq Rn 17 Free

Hartford, Conn. June 19

J. D. Mallory,

Henderson, Texas.

Pay to N. D. Hilliard, Hotel Baldwin, gilt bald edgeways from E. L. Adams, Jr., Hartford. Vigilant

(sig) H. N. Tallman,

Transfer Agent.

It is a curious fact in connection with the "transfer" that in place of the very commonly used D. H. for "deadhead" in the check, the word "free" has always been retained. It is said that the use of this rather grim phrase with the meaning "no charge" dates as far back as the Roman times, when free admission to the circus and the theatres was gained by the presentation of a carved death's head furnished by the authorities.

THE CIPHER MESSAGE.

In the above message it will be noticed that the amount to be paid is indicated by words without meaning to the outsider; and it concludes with "Vigilant," which is understood to mean "identification is required." The "transfer" is, therefore, in part a cipher — a form of message much in favor among patrons of the telegraph. It involves the representation of a word or phrase by a word arbitrarily chosen, and therefore understood only by those concerned; and this is very nearly the dictionary definition of the word "cipher" used in the sense of a secret writing. Its use in telegraphy serves the double purpose of economy and secrecy; and incidentally some forms of it greatly tax the patience of the operator. As the meaning of the cipher is the concern only of the correspondents, there may be as many systems as there are patrons; but among business men the phrases in common use became so numerous that cipher-making itself became a business. At the present time quite a number of systems are in use; so that, to carry on a secret telegraphy, the patron needs only to buy two copies of any preferred code — one for himself, and one for his correspondent. As the words representing the different phrases are generally chosen arbitrarily, any number of English words chosen at random might be taken to form the text of a "cipher" message. But portions of two or three with fictitious addresses, are here given to bring the learner into touch with the reality.

B67 Ha Ks 10 Paid

New York. June 19

L. M. Hazeltine,

Boulder, Col.

Metemperic entire peasoup velvetleaf bondmaid eighteen birthsongs thalarctos each periwig.

(sig) Alpha.

B68 Pq An 11 Collect

North Adams, Mass. June 21

C. K. Thurber & Co.

New York.

Admixed unaided unbias aleak unapplied fetch andiron marauding maroon hairpin.

(sig) E. M. Seymour.

In this last, as in all messages similarly checked, the word "collect" is counted. Of the more difficult forms of cipher that in use by the large business houses of the West furnishes two examples:

C18 Mo Ns 20 Paid
Kansas City, Mo. June 21
L. M. Wetstein,
New York.
Molucris morbescunt desque cow dexterous demulsion facial gildos holzstoss hoodwink hymnifero hamaux marandara vetader no vetachtig motandos fatichera komplot salami.
(sig) Roburn.

D21 Aj So 15 Collect
Indianapolis, Ind. June 24
R. A. Clarkson,
Middletown, N. Y.
Asander unbespeak umsetzbar unbeing boneless maragnon monarch cervelat disallowed each car alamoth arrodeth absorb.
(sig) Schievelin.

Quite commonly these messages contain several hundred words, and no knowledge of English or of any other language is of much aid to the receiving operator; he must watch for each letter, and pen or typewrite the signals as they arrive. It should be apparent at a glance what an indispensable aid to this work the typewriter is. By means of it these unintelligible words are copied in a manner that makes them unmistakable to the reader, and the receiver has no need to resort to the old expedient of "writing in" the Morse characters under the letters imperfectly formed by the pen.

The Cable Message. The high tolls charged for cable service makes the use of cipher in their composition very common. The address and signature of each message is counted, and the former is often transmitted as a cipher word, which is duly registered for reference when needed; for instance, Havicam, London, might stand for Haviland, Campbell & Co., at any address in that city they chose to give. A single example only of a cable message need be given, as the one form is quite generally followed.

52 Yv Kn Duluth 10
Richfig,
Rotterdam.
Ascanilota apilatori makobojoss Koln luhoto
schizandra pythao (sig) Blockland.

Several of the words, it will be noticed, contain just ten letters. This is the permissable limit for one word; if exceeded, the word is counted as two, except in case of the destination, as Constantinople. The correct handling of cables involves many matters of detail in regard to the "count" which requires some little practice to master properly.

A unique form of cipher deserving of mention here, makes a message to consist entirely of groups of figures, usually five in a group and in this form: 17641, 75689, 84356, 09543, and so on through hundreds of groups. For the nought beginning the last group the signals for TW — dash, dot, dash, dash — are sometimes used. This form of cipher seems to be much used in correspondence between the different governments and their representatives and agents.

The circular message, as its name indicates, has a number of addresses with a common text, or body. For this form the senders generally avail themselves of the night-rate service. Except for the plurality of the addresses, each one of which in sending is separately numbered, it does not usually differ in form from the ordinary message.

The "C N. D." The Commercial News Department message is as unique in appearance as it is different in form from the others. The department is an agency for systemized and detailed advice in matters of commercial interest as they transpire in the different exchanges, and in sporting matters to individual patrons and customers. For transmission by the operator the message is usually written either on a pink blank or on a sheet of yellow manifold. One such, picked up at random, reads: "Add Charleston. Quiet 8¾ Sales 50 . . . 2.31" This is a quotation of cotton, and the time when written takes the place of the signature. Another reads:

"Detroit close 2.25
"Dw 84b Red & m 81 N 76 U 75½ . . . 1.15"

To the initiated this means: Cash wheat 84 bid; Red and mixed 81 July 76 September 75½. 1.15 is the Detroit time; 2.25 is the time received in New York. Another, addressed to a summer hotel on Long Island, reads:

"Stocks A81⅝; St 175; MP109⅝; USS37⅞; U 105 . . . 10.16 A.M.," in which A stands for Atchison, Topeka and Santa Fé; St for St. Paul, and so on through the list.

These brief examples give the merest hint of the traffic of this elaborate system; and so diversified are its forms it takes weeks and in some cases months of training to make even a skilled operator master of the service.

The Marine Message. The natural interest of the friends of those at sea in the sighting of their ships, and their desire to know the probable time of their arrival at the dock in New York, led to the organization of the Marine Department, which, on payment of a certain sum, furnishes the information in the following form:

Marine Department, New York, June 2.

George Homer, 351 West 14th St., New York.

Steamer "Columbia" will arrive, unless detained at quarantine, about 6.30 P.M. (Sig.) Manager Marine Department.

This service is almost as old as the telegraph itself, and it remains to be seen how far the wireless system will modify it. It is certainly in this direction that the latter system should first make itself felt.

Of the railway D. H. a short example has already been given as one of the three specimens of the ordinary message. Its marks are the use of initials and groups of figures in which each digit is counted as a word. They are frequently of great length, and require some care in copying in order not to lose the count.

Abbreviated Telegraphy. A notable development of the art in connection with the fast-speed press work involves the use of abbreviations according to a system, and is known among the craft as Code Telegraphy. It was always more or less the custom among press operators to abbreviate familiar and frequently recurring words and phrases when sending to experienced mates; but the introduction of the typewriter gave such impetus to the art that a codified Morse, at the present time, is not far behind the speed of ordinary speech. Beginning with the Morse alphabet, figures and ordinary punctuation marks, the code system first provides an extended system of punctuation covering all the characters and marks that commonly occur in print, as follows: (See page 34.)

For an apostrophe the signal is the same as that given in this

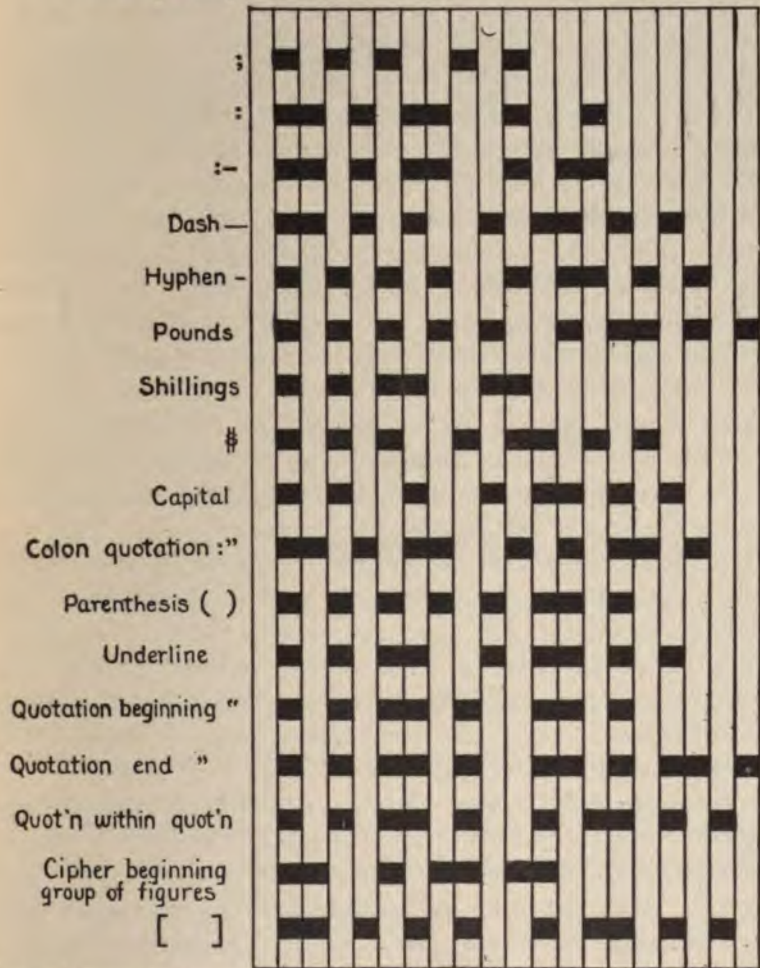


chart for quotation within a quotation; a parenthesis begins with Pn, and ends with Pq; a fraction, as $\frac{3}{4}$, is transmitted 3e4; a decimal, as 89.92, 89dot92; omitted words are indicated by a series of x's; and in sending one or more lines of verse a paragraph mark (– – – –) closes each line.

The system in general use among operators is the Phillips Code, from its inventor, Mr. Walter P. Phillips, general manager of the United Press; and in its arrangement it advances of course from the simple to the complex. Single letters are first made to represent common words and phrases: B, be; C, see; F, of the; K, out of the; Q, on the; and so on through a list that need not be reproduced here, because the entire code can be purchased in book form and contains, besides the code itself, hints for the memorizing and proper use of it. The single letter list is followed by the two-letter and three-letter contractions; and the learner will think it is a far cry from the jog trot of the ordinary text to such expedients as "fap" for "filed a petition," "sak" for "shot and killed," and "sbl" for "struck by lightning." The typewriter alone makes the use of such abbreviations possible. In order that beginners may catch the spirit of the system, the following exercise is written in the code text and then given in full:

"Bt Lafa Plc is smhw Lafa Plc stil. Its trnsfmatn into chp lodgmts is gradl tho su. T sieg gos stedly on, bt t bsiegd hv n yet sucmbd. Ey y t hansm cariags tt rol up & dwn its aves gro fuer and fuer si ey y its pavmts worn bi t fet o ded & gon Nikrbokrs r m fqd bi shaby Germns or slatrnly Italns."

"But Lafayette Place is somehow Lafayette Place still. Its transformation into cheap lodgments is gradual though sure. The siege goes steadily on, but the besieged have not yet succumbed. Every year the handsome carriages that roll up and down its avenues grow fewer and fewer; every year its pavements, worn by the feet of dead and gone Knickerbockers, are more frequented by shabby Germans or slatternly Italians."

Messages for Practice. To extend the student's practice, and further to familiarize him with the appearance and wording of the different forms of messages, the following specimens have been selected. They are arranged promiscuously, so as to afford exercise in naming the different kinds; attention should also be given to the different ways of counting in cable, government, collect messages, etc.

A116P Hk Wn 18 Free.

Portland Me. 27

J. E. Bierhardt, Transfer Agent,

Rome, N. Y.

Pay W. L. Dumont, Arion Club, Central Hotel, Rome N. Y. Japan Alms, Indent from Abner Gaylord, Portland. Caution.
(sig) Wm. Ellerby, T. A.

57 Av Uc 20 Collect
Tb Hartford Conn 4
Adam Mason & Co.,
Ottumwa, Iowa.
Manifoldly mensural parks nacrite distrust nacori crying naively medium mensural nalubu monitory treble namesake monk rudeness Naaman tourmaline, Hawaii
(sig) H. M. Allen & Co.

158N X Rs 17 Paid
Norfolk Va. 4
Chandler Elevating Co.
Great Bend Ind.
Skeptic W. H. McAlpin border route Norfolk western on tantrum tread affording chuckling offers chubby affray more
(sig) L. W. Jay & Co.

14 Wd Fr 12DH.
Marine Dep't, N. Y. 29
M. B. Goldfogle,
International Hotel, N. Y. City.
Steamer Campania will arrive, unless detained at Quarantine, about 8 A. M. tomorrow.
(sig) Manager, Marine Dep't.

273 W 125th St. N. Y.
D. F. S. Delivered ok your 23 today to S. S. Cooper sined Atkinson. (sig) Phila.

In this case "DFS" means destroy former service.

Danville N. J.
Yes have collected 25 cts for msg to Dickerson sined Hall
(sig) Garfield N. J.

191 Kf Gs 16 Paid 8 Extra
Str. Campania off Sagaponack L. I. Nov. 29
via New York 29
Morris, 21 Flushing Ave.
Jamaica L. I.
All well. Dock early Sunday. Don't come down
(sig) H. N. Heldman

The above resembles one received by the "Wireless" and transferred by them to land lines at New York.

133 Ro Py 22 Paid Gov't
Washington D. C. 29
Morning Register,
Dallas, Texas.
Showers Sunday warmer except on the coast; Monday fair in northwest; showers in east and south portions.
(sig) Wells.

119 Fs Ki 11 Paid
Winnipeg Man 29
Lindsay & McDonald
Valley Stream, L. I.
Offer saltcat to saltpeter scalene throe garrulity en route or gallate. (sig) Robb & Parrish.

174 Wr Ta 6 Collect.
South Bend Ind 4
Champion Beef Co.
Pine Island N. Y.
Enkindle gratefully erupt none trundle.
(sig) Baker Packing Co.

114 Gu Ps 8 Paid Night
New Orleans 29
Mrs. S. Dorner, 118 West 119 St
New York.
Will be home Monday afternoon. Tell Ella. Love.
(sig) Joe.

128 F Kn Cable
Havana 6
Hammond,
Calumet (Mich)
Candelabra domiseda 780 calefying.

In the above, the State in parenthesis is supplied by the land line clerk, and is not counted; the group of figures is one word.

193 Yv Wr 12 Paid Repeat back
Philadelphia 31
R. B. Dignam
New Orleans.
Elmpole arundelian bags parable admit actuality rampallian Halpen aliped bags. (sig) C. Emslie & Co.

In this case the words "repeat back" are counted and charged.

... ... 7 Paid Charge
Newark N. J. 29
Adams Ilich & Co. Memphis Tenn.
A. N. Harriman Louisville Ky.
F. J. Farjeon Mobile Ala.
Walter N. Davis St Louis Mo.
No reds; best Jerseys eight twenty five.
(sig) C. W. Allison.

In transmitting messages like the above each operator numbers and times the address of the one which goes on his particular wire; then passes it on to another and so on until all, sometimes scores in number, have been sent.

To Albany N. Y. Dec. 15
B33 487½
34 484 (sig) 10.18

To Salida Colo.
N. Y. Metal Ex. Pig lead 412½
London Silver 22⅜ (sig) 9.10

To New Orleans and Mobile.
C. Adam
31 - 99 - 30 (Sig) 11.43

174 Ro Fc 44 DH
Bridgeport Conn 29
Agent L. S. RR. Co.
Cleveland Ohio.

From Paterson to Cleveland June 1st in D L car 27052 one case brass tubes number 2596 consigned Schneider & Fenkamp covered by Lackawanna line waybill 2774 advise date arrival and delivery quick. (sig) R. J. Camp

By way of introduction to the next topic—Railway Telegraphy—the above series of specimen messages concludes with one more example of a railway DH.

37 Av Ty 36 DH
Springfield Mass 20
E. H. Palmer,
Buffalo, N. Y.

File W, Adams to East Buffalo Wb 111 Dec 8 Christmas trees for D. H. Croley Dunkirk N. Y. deld N. Y. C Dec. 9 on B & A 2718. Please advise delivery. Rush.

(sig) H. C. McCarthy.

Railway Telegraphy. It is well known that the first telegraph line built in the United States was intended for commercial work; but the new art had not long to wait before it was enlisted in the service of the railway. Along their right of way the latter erected poles for the accommodation of their wires to which the commercial companies soon made additions; and, except in the larger towns and cities, one man usually did the work of both. As railways extended and towns multiplied, the work of the latter differentiated from that of the former so that today there are two well defined divisions in the craft; interchange going on between them, however, all the time.

In many places even yet by agreement between companies the railway operator covers the service for the commercial; the latter likewise transmits in great numbers over its wires the service messages of the railway, examples of which have just been given. As compared with these, the student will find that the railway message usually takes an ampler form, more nearly approaching that of a letter. In railway work all messages are "service," and concern the movement of freight and passenger traffic, and the dispatching of trains. All the stock phrases in use are shortened; initials, figures, and abbreviations occur in nearly every line; the "count" which serves as a safeguard to the commercial operator is dispensed with, so that there is all the more need for the operator to be on his guard against omissions.

Again, mention was made in connection with commercial messages of the use of *forms* for races, games, and the like; in railway service this is a marked feature, their number in the case of some leading railways exceeding one hundred.

Then, thirdly, in connection with the purely telegraphic part of the service is the very important work of handling the train orders; first as received from the dispatcher, and then repeated back with the signatures of the recipients.

On a single track railway a crossing order, at one time, commonly ran thus:—

To Conductor and Driver Train No. 21.................

Train twenty-one will meet and pass Special Freight, Conductor Holmes at.... 31

(sig) H. M. Wallace.

H. M. Wallace ....

32 Train twenty-one will meet, etc.

(sig) Conductor and Driver.

More recent usage however is indicated by the following forms; in connection with which it may be premised that the aim is simply to acquaint the student and prospective railway operator with the forms of the messages he will be called upon to handle; but, in order to make them intelligible, some details of the train despatcher's work must accompany them. This can be set down as consisting, for the most part, of (1) orders fixing meeting points for trains; (2) fixing the point for one train to pass and run ahead of another; (3) giving a train the right over an opposing train; (4) giving regular trains the right over a specified train; (5) providing for the use of a section of double track as single track; (6) providing for a single movement against the current of traffic on double track. Then there are (7) time orders; (8) orders for sections; (9) for extra trains; (10) for work extras, or auxiliaries; (11) holding orders; (12) orders annulling or cancelling a regular train; (13) annulling an order or part of an order; and, (14) orders superseding an order, or part of an order.

From the list of train movement forms thus indicated, some of the more important, viz., the first, second, fifth, eighth, ninth items are selected for illustration; the names chosen for the stations are fictitious; but the forms are those in actual use on some of the leading trunk lines.

Suppose a single track, of which Balmain and Allaire are terminals; Eden and Canton are intermediate stations. Train 334 going south is late; it is desired to advance on its time train 331 going north, Eden being the regular meeting place. The despatcher calls up Balmain, Allaire, and Eden and sends the following; C and E being the stereotyped abbreviation for Conductor and Engineer:

31 No. .. Operator, Eden.
31 No .... C & E No. 334, Allaire.
31 No. . C & E No. 331, Balmain.

No. 331 has right of track from Eden to Canton
sig W. L. D. Sup't.

Each operator copying this message must repeat it back to the despatcher, and each one must listen to its repetition by the others.

Another form of crossing order for two trains, one at Eden the other at Balmain, would run thus:

31 No..... C & E No. 332 Eden.
31 No..... C & E No. 329 Balmain.
No. 332 and 329 will meet at Carrolton.

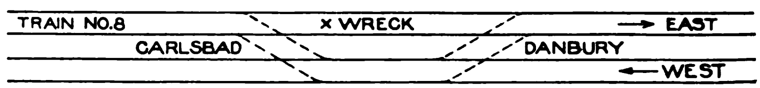
In this and the examples to follow a signature is taken for granted.

For the next movement, viz., the passing of one train by another, the procedure is less formal. It is desired that train 601 should allow No. 1 to pass. In this instance the co-operation of the signal towers, having control of the switches and side-tracks, is enlisted. The despatcher calls up the tower, say at Breslin, and tells the operator that train 601 is next to him, and that he is to side-track it for No. 1. The next tower beyond, say Ashley, is then notified that 601 is in the siding at Breslin for No. 1, so that he may know which train to look for first. Or, the passing may be arranged for in a formal manner:

31 No..... C & E Extra 594, Breslin.
31 No..... C & E No. 6, Breslin.
Extra 594 will run ahead of No. 6 Breslin to Dexter.

In this case the speed of No. 6 must not exceed that of Extra 594 between the points named.

The fifth item presupposes the blockade of one of the two tracks by a wreck—an incident by no means exceptional; the situation being indicated in the cut:—



The station next east of Danbury is Berber. The procedure is then:—

31 No..... C & E all west bound trains, Berber.
31 No..... C & E all west bound trains, Danbury.
31 No..... C & E Train No. 8, Carlsbad.

No. 8 Engine 914 will use west bound track from Carlsbad to Danbury; and has right of track over all west bound trains.

This message is repeated back by all three stations; and under its provisions no west bound trains can pass Danbury until No. 8, Engine 914, has passed east.

During the summer season it is a common incident of the despatcher's work to be called upon to divide into sections trains that, by the addition of extra coaches, have become too heavy for one engine. The two, and sometimes three, sections must be so protected one by the other that, so far as their right of way is concerned, they are substantially one train. Let us suppose train No. 8 at Corbin, going east, has too many coaches for one engine

31 No..... C & E No. 8, Corbin.
No. 8 will carry signals from Corbin to Jersey City for Engine 672.

Engine 672 then takes the second section, and proceeds to its destination under protection of the signal. If a third section is necessary a message similar to the foregoing would be addressed:

31 No..... C & E second section No. 8 engine 672.

A third engine named in this message then proceeds under the protection of the foregoing with a third section of the train.

The above is the method of procedure in case the need for the third section did not appear until after the first section had left Corbin. Otherwise the division into three sections would take this form:

31 No..... C & E Engines 671, 672, 891, Corbin.
Engines 671, 672, 891 will run as first, second, and third section of No. 8 from Corbin to Jersey City.

This form implies the carrying of signals, one for the other, as prescribed by rule; and trains carrying such signals are regarded by other parts of the running service as practically one train.

For the starting of extra trains the signal "19" is used instead of "31" and the order runs thus:

19 No..... C & E Engine 587, Jersey City.
Engine 587 will run extra from Jersey City to Berber

If a regular train is late, and it is desired to give this extra a right to the time of the regular, it is done by inserting in the above message "No. 3 will run 30 minutes late from Jersey City to Berber." All these orders are copied on manifold paper; one copy is furnished to the conductor, another to the driver, while a third is filed by the operator for his guidance and future reference. These examples could be multiplied indefinitely, but it is believed these citations are sufficient to indicate to the learner the kind of service expected of the railway operator in co-operation with the work of the train despatcher.

THE ELECTRIC TELEGRAPH.

PART II.

The principal topics considered in Part I, were the "learner's outfit"; the "one-wire" office with its relay, key, sounder, and local circuit; and the switchboard for the cutting in and out of instruments, and the cross-connection of wires. There are scores of such offices, called branches, in the larger cities; and every town throughout the land has at least one.

An advance is now made to the more complex equipment of a junction station, or town office, to which a score or more of wires converge, and from which they radiate in all directions.

Instead of a "one-wire" set, there may now be noticed on the desks or tables, six, eight, or ten relays and keys; the sounders, possibly less in number than the relays, are operated by a current furnished by storage cells to which energy is supplied by an electric light circuit. The clock on the wall is probably of the "electric" pattern with two Leclanche cells inside. On a shelf are probably two or three sets of apparatus called repeaters; on another table are the duplexes or, it may be a quadruplex, whose principles and manner of operation need careful consideration; and in place of the diminutive single-wire switch of the city branch, or country office, is its more ambitious counterpart with fittings for some thirty, forty, or fifty wires. The handling and care of such a plant calls for skill and experience to which many a commercial operator, doing the work merely of a sender and receiver, is a stranger.

A consideration of the apparatus and methods of work in this larger office is the purpose of this paper; and the apparatus first to be studied is the switchboard. The one shown in Part I is a "single-wire intermediate"; but to accommodate the thirty or more wires now in view a greatly enlarged form is needed. The description of the small switchboard should be re-read, noting that in an intermediate switch two vertical strips are needed for a wire; that is, one strip for each direction of the wire, say north and south; in the switch of a terminal office a wire occupies only one strip.

Of the former class a common pattern is shown in Fig. 9; the diagram representing three pairs of strips out of a 50-strip switch for the accommodation of 23 wires; the gap in the middle represents 19 omitted pairs; the pair on the extreme right has a special use which will be explained later. In all respects the numbers on the small switch shown in Fig. 8, Part I, have been duplicated, except that the top row of discs is reserved for the ground wire; and for a review we shall go over, on this larger board, all the steps taken in connection with the smaller one.

In Fig. 9 the strips are numbered, for convenience, at the lower end from left to right; the disc rows are indicated by the figures down the center. In some patterns of boards the strips are so shaped at the bottom that to join them up in pairs a peg can be inserted. The switch is supposed to be at a station intermediate between Cincinnati and Chicago; strips 3 and 4 accommodate wire 1 South and 1 North respectively; strips 5 and 6, wire 2 South and 2 North; and so on. Disc rows 4 and 5 are connected on the left with one set of instruments; rows 6 and 7 with another set. In the drawing they are shown close to the board, but in practice the instruments are usually at some distance from the board on a desk to which the connections are made by means of office wire. Suppose, first, that the instruments are to be "cut out". Connect with a peg, strip 3 and disc 3; and strip 4 with the same disc 3; wire 1 has now no connection with either instrument, the current simply crosses on the disc from strip to strip. Move the peg in strip 3 to strip 3 disc 4; there is now no connection between disc rows 3 and 4, and the circuit in wire No. 1 is broken. Move the peg in disc 3 strip 4 to disc 5 strip 4; the current in wire 1 will pass through the relay and key connected up to disc rows 4 and 5; and the instruments are now said to be "cut in". In this larger board the ground wire occupies the top disc row, instead of the bottom, so that the discs marked 6 can be used the same as any other numbered row.

Reverting now to the changes indicated in Part I, page 25; for the sake of practice, move the peg from strip, or bar, 3 disc 4 to bar 3 disc G; and the peg from bar 4 disc 5 to bar 4 disc G; the wire from each direction is grounded. There are now two independent circuits each with a battery at one terminal only; Cincinnati and Chicago are cut off one from the other; the way-station instruments also are cut out. In order to "cut in" on the south section of wire No. 1, remove the peg from bar 3 disc G and insert it in bar 3 disc 5; put a peg in bar 1 disc 4, and another in

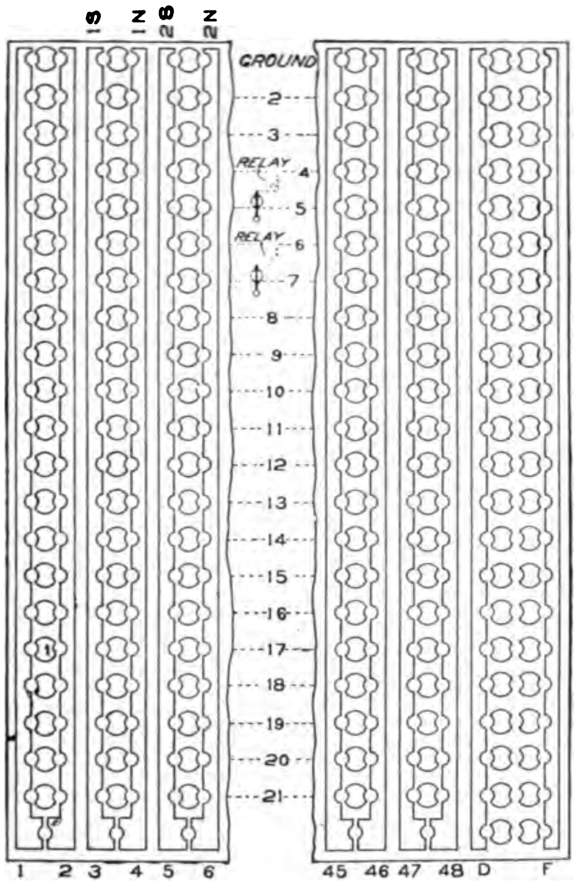


Fig. 9.

bar 1 disc G. The current from Cincinnati must now pass through the relay and key at the side of the switchboard before reaching the ground at bar 1 disc G. The peg having been restored to bar 3 disc G, the same set of instruments, or a different set connecting with disc rows 6 and 7, can, in a similar manner, be cut in on the north section. Restore the pegs to bars 3 and 4 disc 3, and the terminals Cincinnati and Chicago can now work with each other, but neither of the instruments at the side of the switchboard is in the circuit.

The letters D F on the extreme right hand of Fig. 9 stand for the words "double flip"—a device more commonly used in a terminal than in an intermediate office; but it may as well be explained here. In a board like that in Fig. 9, whether terminal or intermediate, each strip has underneath it a "flip", or spring-jack for the insertion of a wedge; usually the pairs of strips on the extreme left and right are set apart and joined in pairs by a wire behind the board. Strips 49 and 50 are practically one bar with two flips at the lower end—hence the name. A board like that in Fig. 9 is often part of a larger system; it may have a similar section on the right and left. The "double flip" enables the switch operator to desk and furnish battery to a wire coming in on another section, by running along on one of the disc rows. The twin discs shown in Fig. 9 have reference also to the presence of a companion section on the right-hand side; in such a case the discs on the extreme right of Fig. 9, row for row, would be connected with it; and, by inserting a peg between the twin discs, rows of like number in the separate sections may be joined, making them continuous across as many sections as desired.

Besides the cutting in and out of his own instruments, it is one of the duties of the intermediate station operator correctly to cross-connect wires at the request of the wire chiefs. He may be asked, for instance, to connect 1 North to 2 South, and 2 North to 1 South. Remove the pegs from bar 3 disc 3, and bar 4 disc 3. Peg bar 4 disc 2; bar 5 disc 2. Peg bar 6 disc 3; bar 3 disc 3. The current on 1 North crosses disc 2 to 2 South; the current on 1 South crosses disc 3 to 2 North. While this cross-connection stands, care must be taken to connect no other wires on either of the disc rows 2 or 3. The test station may have instruments, as shown in Fig. 9, connected up to disc rows 6 and 7. If it is desired to put this instrument in circuit on the wire 2 North to 1 South, remove the pegs from bar 6 disc 3, and from bar 3 disc 3. Peg bar 6 disc 6, and bar 3 disc 7. To facilitate the correct tracing of the different disc rows, it is common to alternate four rows of specially marked discs with four plain ones. To make any cross-connections and combinations of wires that may be needed, the operator needs only to get clearly before him the relation of bars and discs one to the other, remembering that the several rows of discs have no connection with each other or with the bars except by means of pegs.

Recent Form of Switchboard. The pattern shown in Fig. 9, although in very general use, has some defects for which a remedy is sought by a change of form. The connections for "in" and "out" on the top side only of the board require two strips to a wire—an arrangement which is wasteful of space. There has recently been installed in a suburban test office near New York an entirely new form of switchboard for intermediate stations in which the wires pass in at one side and out at the other. A 50-wire board of this pattern is seven feet in height, and thirty-three inches in width. The lower part resembles somewhat a long-distance telephone cabinet; the shelf is thirty inches from the floor, and the

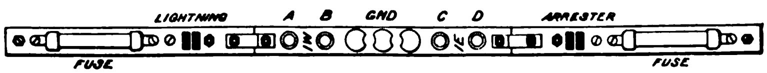


Fig. 10.

space underneath is taken up with the slack of the cords. On top of the cabinet are strips, like that shown in Fig. 10, placed one above the other to the number of say fifty, supported at the corners by four vertical bars of angle iron resting on the floor. The strips are of wood, one inch wide, each consisting of three parts. On each of the end parts are a fuse and carbon plate lightning arrester; in the middle part are four holes, A, B, C, D, for type jacks, and three discs. Between the holes for the type jacks is a tag for marking; the wires in the drawing are 1 West and 1 East. Extending up both sides of the switch are the wires contained in cables, parting with their conductors one by one and making connections with the fuses at each end of the strip.

The middle portion of each strip is ten inches long; and a side elevation is shown in Fig. 11. The four type jacks are connected in series as represented; between the two inner ones are three discs—the middle one grounded; a peg inserted on one side or the other of the center disc will ground the wire in the direction desired. The inner pair of jacks is for patching. In building up the switchboard the strip next above the one shown would be 2 West and 2 East. Each cord is fitted with an automatic slack take-up, as shown, and cross-connections are made by means of single cords and connection plugs F and H. To cross-connect 1 East to 2 West it is only required to place one of the plugs F in the patching jack marked 1 East, and the other plug H in the jack 2 West. In the diagram 1 West appears grounded by means

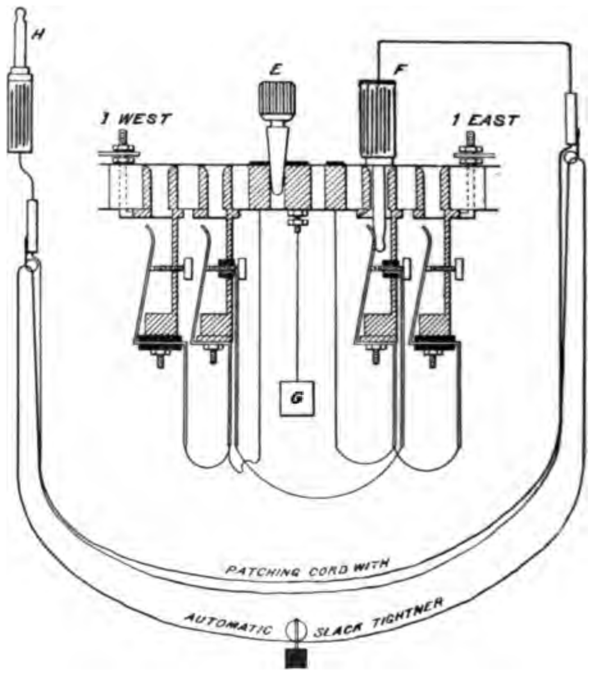


Fig. 11.

of peg E. The outside pair of jacks is used for inserting loops; also to cut in test and desk instruments. The disadvantage in this form of switchboard is that the continuity of the wire depends on the perfect contact of the four springs with the pins behind them.

Figs. 10, 11, 12 and 13 are from a "Pocket Edition of Diagrams" by Willis H. Jones. They are reproduced through the courtesy of the publisher of *The Telegraph Age.*

An inspection of the diagrams in Part I yields a fair inference that each relay must have its own sounder; but the opening lines of this paper in which it is said that the sounders, possibly less in number than the relays, are operated by a storage current, hint at a departure from this rule. In former days the telegrapher sometimes made his first efforts at invention in a plan to economize, by making one sounder do duty, at different times, for three or more relays. But the field of devices for locals is well covered

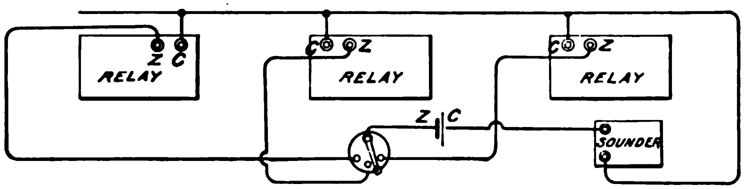


Fig. 12.

now; one of the results is shown in Fig. 12 which represents an arrangement of circuits in which one sounder can, by means of a switch, be worked in connection with three relays. The diagram needs no description, but the connections should be traced in each case; the lever resting on the right, middle, or left points cuts in the corresponding relays, in each case forming an independent local circuit. At junction stations, where passing trains are likely to make considerable noise, one sounder may be insufficient; in this

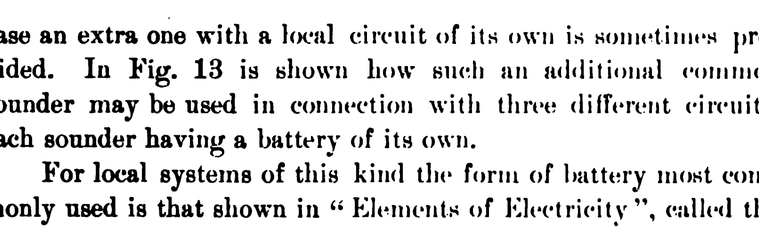


Fig. 13.

case an extra one with a local circuit of its own is sometimes provided. In Fig. 13 is shown how such an additional common sounder may be used in connection with three different circuits, each sounder having a battery of its own.

For local systems of this kind the form of battery most commonly used is that shown in "Elements of Electricity", called the Daniell, or "blue-stone", cell. Better still is the modification of it shown in the same paper known as the "gravity" cell in which the zincs can be so fitted one into the other, that no portion of that metal needs to be thrown away or wasted. But not even the local battery system has escaped the spirit of change; and in many recently-equipped offices the zinc and copper type has been replaced by the storage cell, so called. The name implies the giving out of a current derived from another source—generally a dynamo—but the idea requires some modification, as will appear later on.

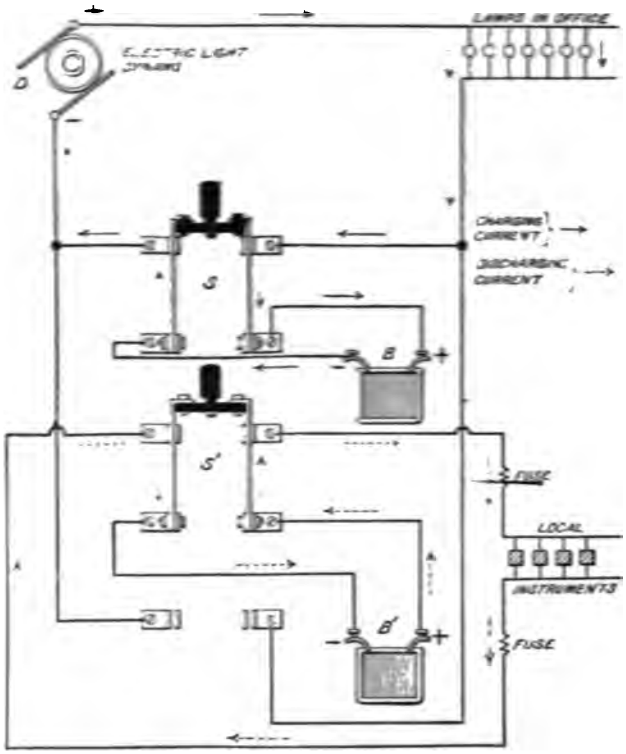


Fig. 14.

In Fig. 14 is shown a storage cell system fed by a dynamo which is also the source of energy for an electric-light plant. There are two storage cells, one of which, B Fig. 14, is in the same circuit with, and receives the current in the same manner as, the lamps. The other cell, B', is disconnected for the time being from the dynamo, and is represented as supplying the current for a number of sounders arranged in multiple on the lower right. It will be apparent on examination that the method of connecting up the lamps in one circuit and the sounders in the other is the same.

In the opening paragraphs of "The Electric Current" the student has learned something of the laws of resistance. His attention is called at this point to the difference between the series and multiple arrangement of sounders. In the former, the resistance in ohms offered by the coils is the resistance of one sounder *multiplied* by the number of sounders; in the multiple system it is the resistance of one sounder *divided* by the number. A pair of knife switches, S and S′, shown in Fig. 14, is the means by which storage cell B,′ when it is exhausted, can be cut in on the same circuit with the lamps; its place in operating the sounders is then taken by the freshly charged cell B. In Fig. 15 the construction and action of the double knife switch is clearly shown. When turned from the position they hold in the diagram they make a new series of connections with the result already indicated.

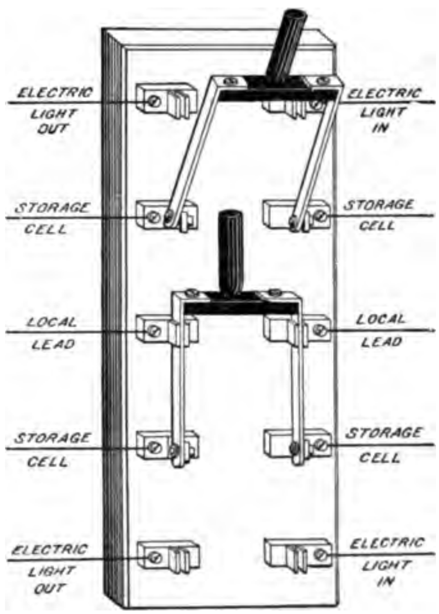


Fig. 15.

The Dynamo in Telegraphy. Within little more than a quarter of a century this appliance, regarded at first somewhat as a curiosity, has advanced to the place of an indispensable and well-nigh omnipresent help in the mechanical and technical world. In countless shops and factories its familiar hum and vari-colored sparking can be detected in out-of-the-way corners; while in power houses its more developed and, in some cases, giant form fully justifies the remark of the scientist Faraday when he saw the first dynamo in operation: "That was my child; but you have made a man of him." In the field of telegraphy its principal uses are to charge storage cells, and supply current for the main lines. In the former operation, the cell is said to be fed by the dynamo; and, as already illustrated, it is commonly carried on in combination with the supply for an electric-lighting system. The "feeding" consists of a chemical change in the cell, whose elements, when the charging ceases, give up in the form of electricity the energy thus imparted.

As the dynamo is the source of energy for the storage cell, and for the operation of the different forms of main line apparatus, the need arises for a brief statement of the principles underlying its construction. In so doing, some words and phrases not hitherto

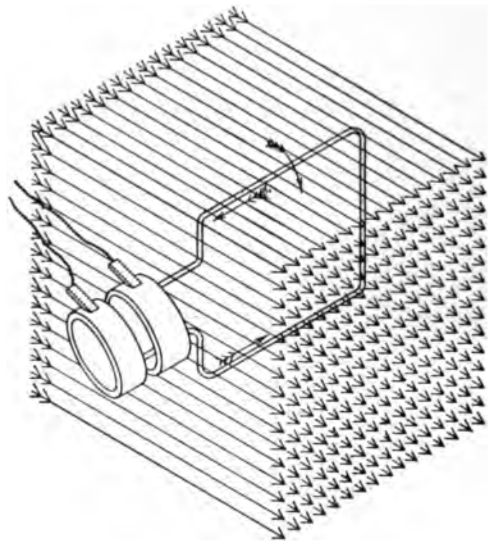


Fig. 16.

used come into view; and a definition of them, in connection with familiar forms, is first in order.

The *cores* in the electromagnet of the sounder, as the student knows, attract the armature. The free ends of the cores are the poles; and if a penknife is placed near, it is drawn towards the core with a force that increases as the distance lessens. Similarly, if a small piece of metal is held near the poles of a toy magnet in the horseshoe form, the attraction is marked. The space between the poles alike of the electromagnet and the toy magnet seems full of invisible stresses whose mechanical effect is like that of thousands of stretched rubber threads which tend constantly to contract. These stresses are called lines of force; and the space in which their influence is felt is called the field of force. These lines are inseparable from every form of magnet, permanent or electro; in the case of the earth, which is itself a great magnet, their effects are seen in the action of the magnetic needle placing itself parallel to the lines of force between the north and south poles; in the case of an ordinary magnet, the lines seem to appropriate to themselves any material which will shorten their journey through the air space; and, if the piece of metal is free to move, the lines tend to place it in the position which will shorten their pathway the most. Another, and the most common, name for the space occupied by the lines of force is the *magnetic field*. It is graphically shown in Fig. 16 in which is represented also the simplest form of dynamo. The arrows represent the lines of force between the magnetic poles; and, revolving therein, is shown a single conductor cutting the lines of force at right angles. Now comes the principle which underlies the generation of the electric current by means of the dynamo: If a closed conductor is rapidly revolved in a magnetic field an electric current is set up in the conductor. The collector rings and brushes conduct to the outside circuit the current thus generated.

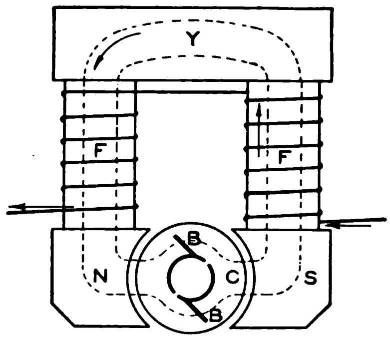


Fig. 17.

In Fig. 17 there is shown in outline form a simple dynamo; the yoke Y connects the field pieces FF, upon which are wound the field coils; the latter is charged by an external current in the direction of the arrows. In an intense magnetic field, between the pole pieces N and S, is the armature. It is made up of the core and a complete circle of conductors like the one shown in Fig. 16; a large number of conductors being needed to generate a continuous current. The conductors are made to terminate in a series of strips separated by insulating material, and bound together in a cylinder to form the commutator marked C; the collecting brushes BB correspond to the copper and zinc poles of a voltaic cell.

A gas or steam engine is usually the motive power for a dynamo; a common type is shown in Fig. 18 with the belt pulley at the left; in this form it illustrates the definition of a dynamo given in the text books as "a machine for converting mechanical energy applied at the pulley into electrical energy given off at the brushes."

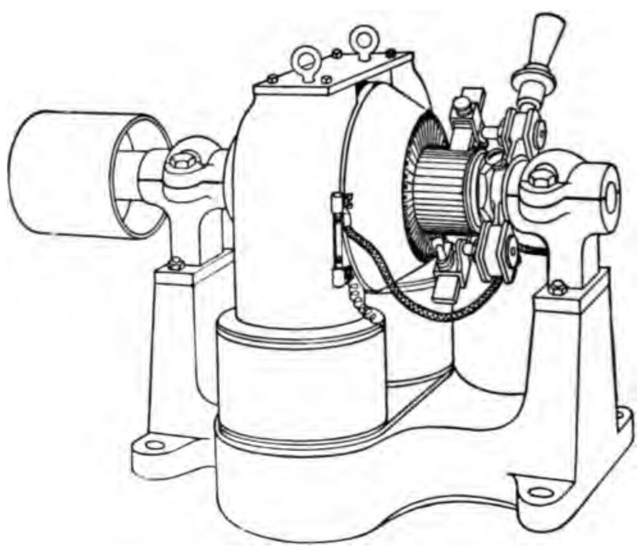


Fig. 18.

One use of the machine, namely, to furnish current for a system of local instruments, is illustrated in Fig. 14, but its more important function in telegraphy is the supply of the current for the main lines. The different circuits to be supplied may vary in length from 50 to 500 miles; and, as nearly the same quantity of current—say $\frac{1}{25}$ of an ampere—is required in each case, the voltage, or pressure, must vary accordingly.

A series of dynamos connected together upon the same principle as a series of cells in a battery is outlined in Fig. 19, showing how this may be done. One terminal of machine A is grounded, and from the connecting points of the brushes the wires 1, 2, 3, 4, and 5 are led to the horizontal rows of discs on the terminal switchboard. In practice they are commonly made a part of the larger board similar to that shown in Fig. 9; but, for the sake of clearness, it is represented here as distinct. Each vertical bar represents a main line wire; the horizontal lines are rows of discs to which are connected the wires carrying the current for distribution. In Fig. 19 wire 1, connected to one of the disc rows, furnishes 70 volts (the voltage of a Grove cell is about 1.5); wire 2, 140 volts; 3, 200 volts; 4, 260 volts; 5, 325 volts. It is necessary only to connect, with a peg, a disc and bar to supply any wire with any desired voltage. A plant of the capacity indicated in the diagram can be made to furnish current for 1,000 lines, yet its compactness is such that it may be installed in a small room.

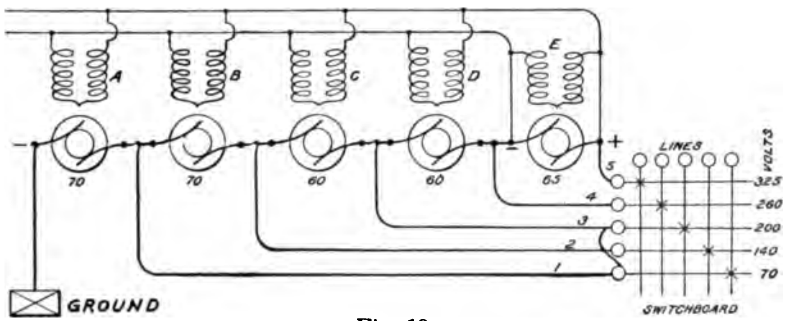


Fig. 19.

The advantages of the dynamo over the voltaic cell are:

(1) Its low internal resistance making possible the supply of so many wires.

(2) Economy in maintenance.

(3) The space occupied is much less.

(4) It does away with the unhealthy conditions of a fume-laden battery room.

The Open Circuit System. Before dealing with the topic of Single-Line Repeaters, let us discuss a system much used in England, known as the "open circuit", as distinguished from the one in general use in the United States, Canada, and Mexico, described in connection with Fig. 6, Part I. This is known as the "closed circuit", in which the circuit is first broken by opening the key switch as described, and the signals are transmitted in the manner now familiar to the student. The open circuit system is illustrated in Fig. 20; in it may be noted the difference in the connections of the key as compared with those of the American system. In the latter, as may be seen by reference to Fig. 6, Part I, the battery, key, and relay coils are in series; in the former, the ground connection divides, one branch passing through the relay coils to a point in the base of the key against which the lever carrying the main line normally rests. The other branch connects the battery to a different point of the base. It may be seen from the diagram that when both keys are making contact with the backstop there is no current on the line, and the relays are open. Depress one of

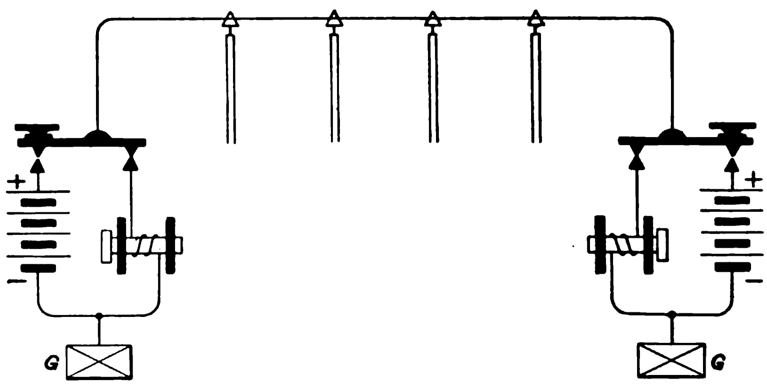


Fig. 20.

the keys and the current, passing directly to the line, closes the relay at the distant station.

In this arrangement there are two advantages over the American, or closed circuit, system:

(1) The battery is in use only when signals are transmitted.

(2) By the cutting out of the relay at the sending station the resistance of the circuit is reduced.

The disadvantages are:

(1) The operator hears his own sending on the key only.

(2) The system does not admit the cutting in of intermediate stations.

The closed circuit arrangement allows as many as twenty-five or thirty offices between terminals; and the batteries, placed one at each end of the line, are more likely to receive skilled attention.

SINGLE-LINE REPEATERS.

In the junction station, or town office, we now have in mind a set, or sets, of repeaters—an important feature in the equipment, and the one next to be considered. The limit of the Morse single line, in good weather, is ordinarily about 450 miles; it is one-half or one-third of that in rainy spells when extra repeaters are cut in. The repeater is a means by which the relay at a distant terminal of one circuit is made to operate a key in a second circuit. The distant relay of the second circuit may operate a key in a third; and so on. The circuit of say 1,500 miles has thus the advantage of batteries at needed intervals; the distance between repeaters being determined by the conditions already indicated; and it has not been found expedient to exceed very much the distance first given.

There are many different forms of repeaters; and from among the score or more that have been in use at different times selection is made of the three commonly regarded as the best—the Milliken, Atkinson, and Weiny-Phillips. The same result is attained in each, but by somewhat different means; all three are of the automatic class—so called because they permit the terminals to break without the aid of an attendant.

Fig. 21 shows the **Milliken** repeater in theory. It consists of two relays of special construction, two transmitters, two main batteries, M B, a pair of local batteries, L and L', and a pair of extra locals. Tracing the connections of the local batteries, they are found to be wired through the local points of relays E and W, one for each; and through the coils of transmitters T and T'. The extra locals are wired through the back contacts of transmitters T and T'; and in the same circuit are the coils E' and W'. In the construction of the relay the peculiarity is that, in combination with the electromagnet and upright armature of the ordinary relay, there is an extra magnet with a pendent, or hanging armature marked P in one and P' in the other, Each one is so placed that, when released from its magnet, the tension of a spring forces it against the upright armature and holds the local points closed ... the student in tracing out the different connections ... circuits are marked by dot and dash lines; the lo... lines; the main lines are in full lines. ... est

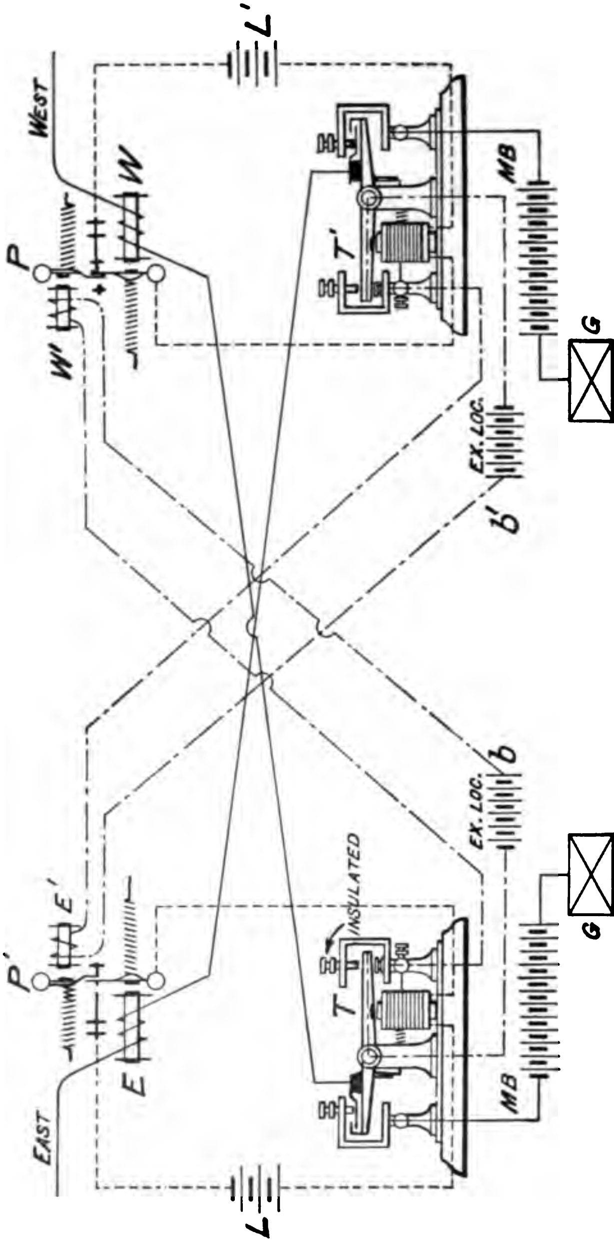


Fig. 21.

are supposed to extend in each direction to terminals, it may be, 400 miles distant. When the circuits are at rest, the armatures of the instruments are attracted by their respective cores, and are said to be closed.

Recall now the definition of a repeater, and notice in the description to follow how the transmitter in the East set acts as a key in the West wire, and *vice versa*. Suppose the distant East station opens and writes; the operator opens the local points of relay E, and this opens transmitter T; through its tongue and post passes the West wire, and it, therefore, is opened. The opening of the West wire should open relay W and transmitter T′; and the opening of transmitter T′ would open the East wire which passes through its tongue and post. But the opening of the East wire when the distant East is sending is just what the repeater is intended to prevent. When transmitter T opens, the extra magnet W′, held closed by battery *b* through the back points of the transmitter, also opens; the pendent armature P is released, falls back, and holds closed, by the tension of its spring, the upright armature of electromagnet W. This prevents the opening of transmitter T′; and the East wire is not allowed to open in the latter instrument. Transmitter T′ can be opened only by opening a key in the West wire, either at the repeater (key not shown in diagram) or, normally, at the distant West station.

When the distant West writes, the action begins with the West relay W the same course as that just described; in this case the pendent armature P′ holds closed the transmittter T, and the West wire passing through its tongue and post.

The Atkinson Repeater. Probably the best of all the repeaters in general use is the Atkinson, the theory of which is shown in Fig. 22. The apparatus consists of two relays of the common type, two transmitters, two main batteries, a pair of local, and another pair of extra local, batteries. The local batteries belong to circuits which, it will be noticed, are marked one with dots, the other with dots and dashes, the same as in the Milliken repeater. On the East set the battery is marked MB, relay E, extra sounder E′ (operated by battery *b*′), and transmitter T; the West set is lettered to correspond. The wires marked East and West extend, of course, in each direction to distant terminals. S[illegible] dis-

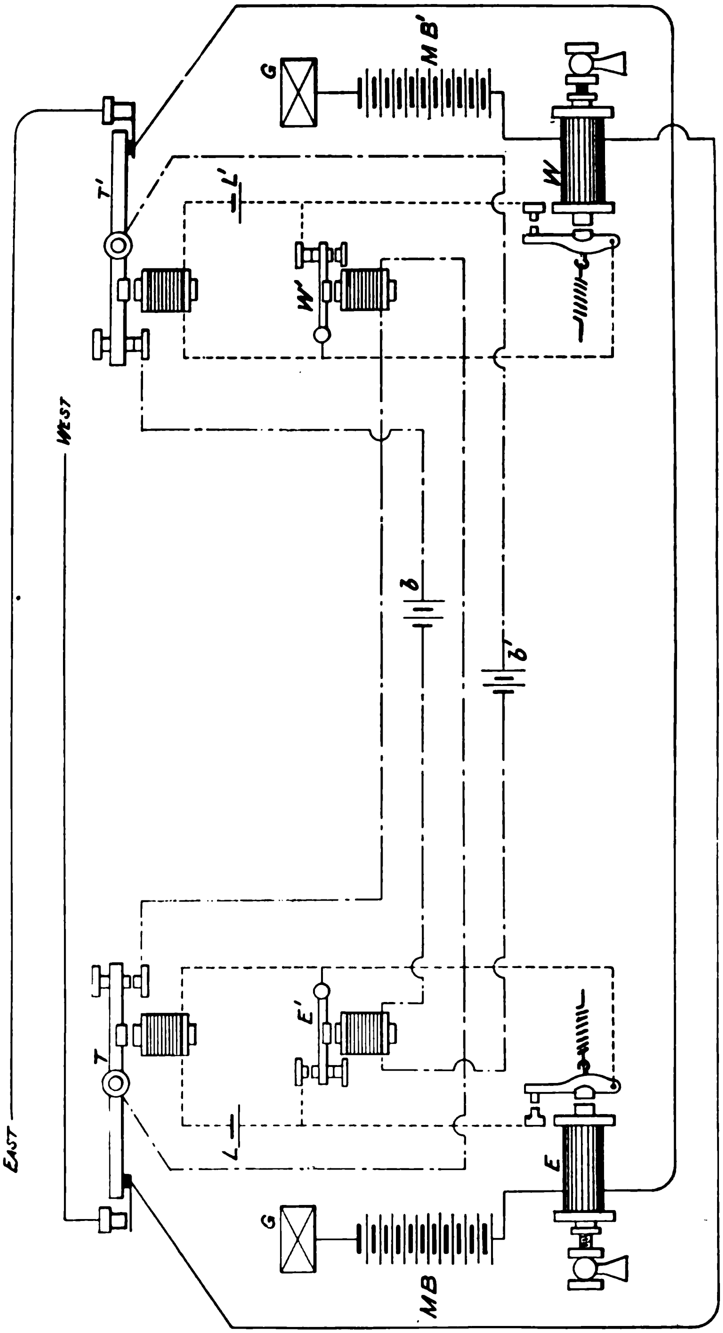


Fig. 22.

tant East opens his key; he thereby opens in rapid succession relay E and transmitter T, which, in turn opens the West wire and relay W. The opening of the local points of the latter instrument would ordinarily open transmitter T', and therefore the East wire which passes through the tongue and post of transmitter T'. But here again the opening of the East wire, when the East side is sending, is prevented by a device characteristic of this repeater. When transmitter T opens, the current passing through W' is broken; the armature of W' is released and, falling against the backstop, it bridges the points of relay W, so that transmitter T' is held closed and, with it, the East wire. As in the Milliken, transmitter T' can only be opened by opening the key on the West wire either at the repeater or, normally, at the distant West station.

When the latter opens his key the action begins, as already described, with the West relay W and follows precisely the same order, in the latter case the magnet E' holds closed transmitter T. Notice that, in describing the action of this repeater, the language used is very similar to that employed in connection with the Milliken.

These two forms of repeater afford illustration sufficient for a good understanding of the principle; one more kind is added because, up to a recent date it was in general use by one of the large telegraph companies; and, more especially, because its construction involves the principle of differentiation in magnet coils which plays so important a part in duplex telegraphy. A description therefore forms a convenient stepping stone to the subject of multiplex work, which opens up a new and interesting field.

A theoretical diagram of the **Weiny-Phillips** repeater is shown in Fig. 23. As in the Milliken, there are three distinct sets of circuits in duplicate; that is, one set represents the East, the other the West side of the apparatus; and in all three diagrams, Figs. 21, 22, and 23, the parts performing like functions are similarly outlined and lettered. The connections of the main line (full line), and of the local (dotted) circuits are identical with those of the Milliken. But, instead of the extra magnets E' and W' and the pendent armatures P and P' of the repeater last named, there is a device which effects the same end; and, for the reason already indicated, it requires some attention because of the new principle involved.

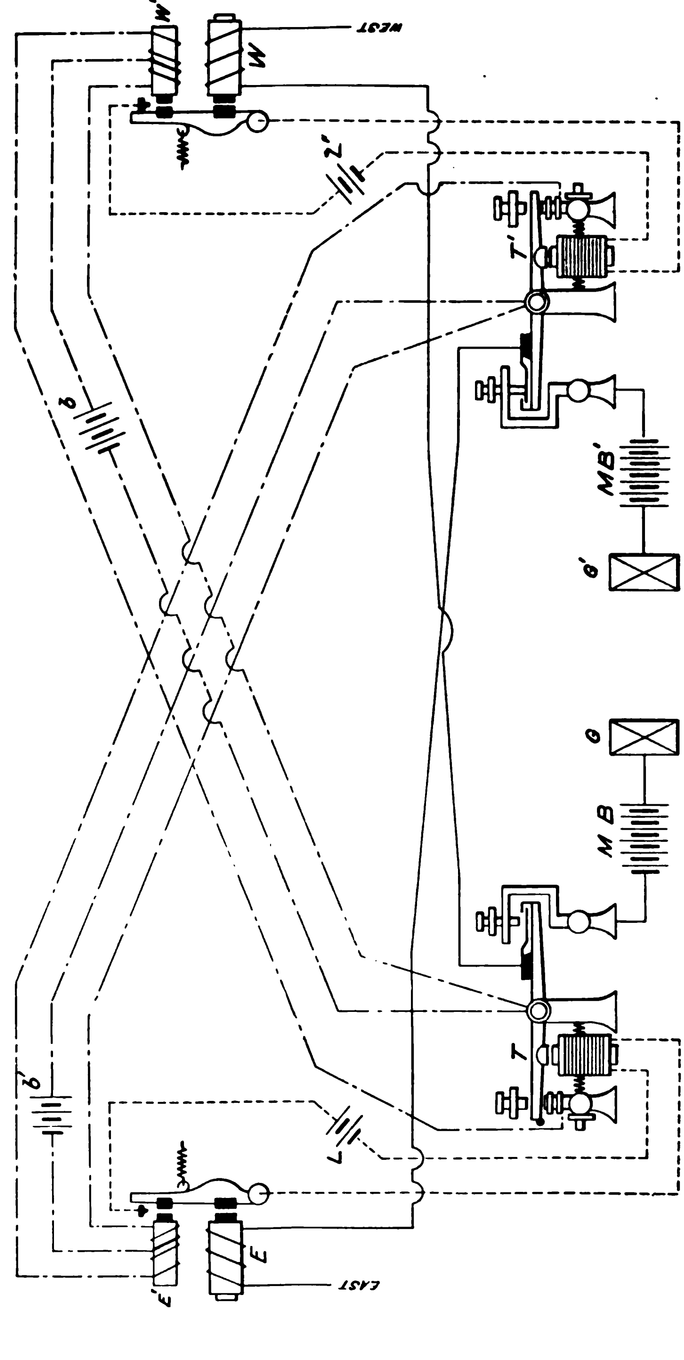


Fig. 23.

In E′ and W′ we have an iron shell enclosing a straight iron core and its winding. The combination of shell and core performs the same functions as the parallel cores in the common type of relay. Trace the wire from battery *b* to the core W′; at a point just above the core the circuit splits; one part winds round the core to the left, and goes to the middle point of the lever of the transmitter; thence back to the zinc pole of battery *b*. The other part goes to the right, and back to transmitter T at the under-stop of the lever. Each division of the magnet coil contains the same number of turns of wire round core W′. When transmitter T is closed, since the lever makes contact with the under-stop, the current from battery *b* traverses the coils of core W′ in opposite directions; the result being that no magnetic pull is produced in the core. But note the effect when transmitter T is open. One of the circuits that passes round the core is open; the neutralization of the current in the other division of the circuit is impossible; the core at once becomes an electromagnet capable of holding the armature at the needed moment. A winding of this kind allows the core to be energized by the *difference* in the strength of the currents in the two divisions; such a core is said to be differentially wound. If currents equal in quantity pass round the coils of core W′ in opposite directions, their magnetic effects are nil; if the currents are unequal, or if one current is nothing and the other any given quantity, the core is energized and will attract its armature.

Notice now the operation of this repeater, in effect identical with that of the others. The distant East station opens his key; this opens relay E, then transmitter T, the opening of which opens the West wire passing through the points of transmitter T. The opening of the West wire would open relay W, transmitter T′, and therefore the East wire which passes through its points. The last opening is the one the repeater is planned to avert. When transmitter T opens, one circuit round the core of W′ is opened; the core is energized and holds the armature of relay W closed, so that transmitter T′, through whose points passes the East wire, does not open.

When the distant West breaks and sends, the same action begins with the West relay and follows the same course. The distant East and West can then work with one another repeater, and have the benefit of the main line batteries at the repeating station. This is the sole purpose of a repeater; in every other respect it is a disadvantage, introducing in a circuit two sets of apparatus which need careful adjustment and considerable attention.

MULTIPLEX TELEGRAPHY.

The Stearns Duplex. In the description of the Weiny-Phillips repeater, the differential winding of a single core was illustrated; and the fact explained that such a magnet is operated by the difference in the strengths of the currents passing through the coils. If the two cores of a single-line instrument are wound in the manner described, we have a form of relay known as the

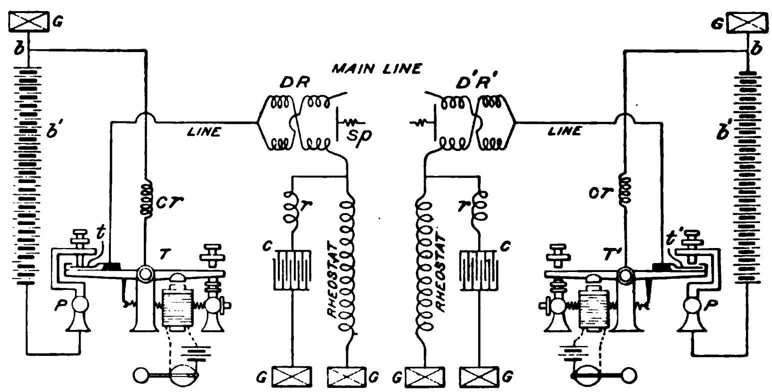
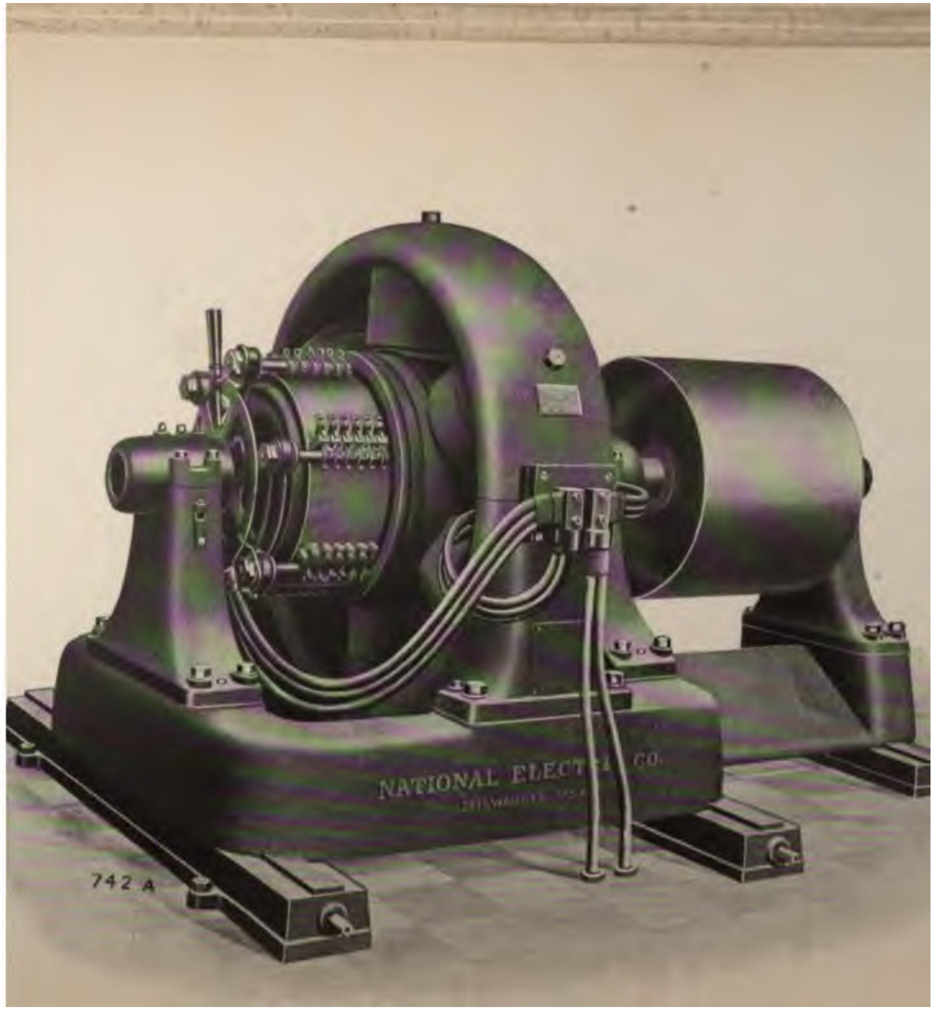


Fig. 24.

Stearns differential; with this and a few accessories a line can be made to carry signals in opposite directions at the same time. In other words, the wire can be duplexed; and the theory of it can be explained and understood from the diagram, Fig. 24, in which the apparatus and connections for both terminals are shown. D R and D′ R′ are the differential relays; the gap between them is supposed to be bridged by the main-line wire, which may be 450 or 500 miles long.

In addition to the relays and batteries, the essentials for each terminal are a transmitter, rheostat, some resistance coils, and a condenser. Each of these may be seen in its place in the diagram; the rheostat marked in full, the others with the first letter of the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name; the local circuits for the relays are not shown. One pole of each battery is grounded; the other makes contact with the post P of the transmitter; and, as the sets are duplicates, one only needs to be described.

The lever of transmitter T makes contact with the ground through a coil *c r*, which compensates for the internal resistance of the battery, making the resistance of the circuit the same whether the transmitter is closed or open. The lever carries, on an insulating pedestal, a spring or tongue *t*, to which is attached the line wire; it makes contact with the post P (battery) when the transmitter is closed, and with the lever (ground) when the transmitter is open. This instrument is seen to be a device for transferring the line wire from the battery to the ground contact without interrupting the circuit; and it is operated, as shown, by means of a key in a local circuit. The line wire can be traced from the tongue *t* to the point of division—technically known as "the split"; the little semicircle in the diagram indicates in every case no connection with the wire underneath; each division of the circuit passes through two spools of the relay; one branches off to the main line, the other through the rheostat to the ground. By way of introduction to the apparatus last named, take the case of a motorman of a trolley car in motion. His left hand controls a radial arm surmounting a box which extends down to the platform, and contains a number of lengths of coiled wire through which the current passes on its way from the trolley wire to the motor. Every move of the radial arm in one direction or the other means more or less of current, and therefore more or less of speed in the motor. The coils resist the passage of the current, and the box is therefore a current retarder, or rheostat, which is the same thing. In a similar manner, either by a radial arm or, more commonly in a duplex, by means of pegs making contact between discs in which the resistance coils terminate, the current may be regulated in the circuit of which the set of coils marked "rheostat" is a part; that portion of the circuit from the point of division to the ground being called the artificial line.

The purpose of the rheostat is to divide the current passing through the relay coils equally between the main and artificial lines; and, as already intimated in connection with the repeater, this can be done by making the resistance in the rheostat equa that of the 450 or 500 miles of wire in the main line—anywl from 5,000 to 10,000 ohms. When this condition is establis it does not matter, within working limits, what the size of batt is; the current will pass through the relay with no apprecia magnetic effect upon it; and the duplex is said to be "balanced

How to Balance. Suppose the terminals to be provided v duplex sets and batteries as shown in the diagram, and a main connecting them. First approximate the balance by pegging rheostat to 5,000 or 6,000 ohms in clear weather for a line miles long. Ask the distant office to "open". Notice in con tion with transmitter T' that this opening grounds the wire at distant end. There is now no battery on the line but your o lower the tension on the spring *s p* and, by means of the p vary the resistance in the rheostat (the home key being clo until the cores of the relay show no appreciable attraction for armature. This done, open and close the key a number of tin a slight click of the sounder with each movement of the key probably be heard—an effect which it is necessary to elimin It is with the dynamic, or current, form that, up to this time have been dealing; but the false signal just mentioned in con tion with the duplex brings to notice, for the first time, electri in the form of *charges* upon the wire, and therefore called st It presents itself as a disturbing element in connection with du work; and the remedy for it is a movement in the artificial round the relay coils in a direction opposite to that which ca the 'kick'; the means for producing it is the apparatus in Fig marked C, for condenser.

For a statement of what static electricity is, and certain f of the condenser, see "Elements of Electricity". In the diag the lines represent sheets of tin foil; the spaces mica, paraf paper, or some insulating material; one set of the sheets n connection with the line; alternating with them, as show another set which makes contact with the ground. The sl with the insulating material, are enclosed in a box, and the nections mentioned are made in one case by means of a bar, a the other by means of a set of discs so placed that, with a few the number of sheets in actual use can be varied; and, by r of an adjustable set of coils *r*, the charge and discharge can be assimilated to that of the main line.

On the condensers commonly used in telegraphy the discs are usually five in number, and are marked 40, 32, 16, 8, 4 to denote the percentage of tin-foil area connected to the disc. If pegs are inserted uniting the bar with discs marked 4, 16, and 40, 60 per cent of the capacity is in use, and the charge and discharge will be in just that proportion. A condenser usually bears a stamp as 2.5 M F, or 3 M F. The M F stands for micro-farad, which is the practical unit of capacity; and is about equal to that of three miles of an Atlantic cable.

With the duplex in operation there is, on the closing of the transmitter, a charge through each pair of relay coils and, on the opening of the transmitter, a discharge through each pair of relay coils the same in quantity and at the same instant; and in each case the movement in one pair of relay coils neutralizes that in the other.

When the "kick" has been cleared, the distant station is asked to write; and it will be found that the outgoing signals do not interfere with the incoming, because the duplex has had a static, in addition to its first, or ohmic, balance. The distant station then goes through with the same process, and the sets are ready for service.

All the accessories having been described, it remains to trace in detail the effects of the currents on the relays in every position possible to the transmitters. In the diagram, on the left, the battery has zinc to the post and copper to the ground; at the other terminal, on the right, copper is to the post and zinc to the ground. The duplex would work if the batteries had like poles to the line; but we shall consider them in the manner shown. In operation, four conditions are possible, and they may be tabulated as follows:

T closed	— to line	T' closed	+ to line	D' R' closed	DR closed
T open	G " "	T' closed	+ " "	D' R' open	DR closed
T closed	— " "	T' open	G " "	D' R' closed	DR open
T open	G " "	T' open	G " "	D' R' open	DR open

It will appear from this that the differential relay at one terminal obeys the transmitter at the other. We shall see how this works out in practice. A line 450 miles long usually has a voltage of at least 150 at each terminal; and, as only 25 cells are represented in the diagram, each cell must be supposed to represent 6 volts.

First, when T and T' are closed; the batteries unite their energies, giving on the main line a current of $\frac{1}{25}$ ampere, or 40 milliamperes. On the artificial line, in the relay coils at each terminal, there is a current from the battery at that terminal through a resistance in the rheostat equal to that of the line, say 20 milliamperes, because the voltage in each case is only one-half that of the united batteries on the main line. In the coils of each relay there is a difference of 20 ma and both remain closed.

Next, open transmitter T. The battery at the left is cut off, and the line is grounded through a compensating resistance C R equal to the internal resistance of the battery. On the artificial line in relay D R there is no current; on the main line there is a current of 20 ma from the distant battery; relay D R remains closed. On the artificial line in relay D' R' there is a current of 20 ma which neutralizes the current of 20 ma on the main line, and the relay D' R' opens; in other words, it obeys transmitter T.

Next, close transmitter T and open T'. This is the phase shown in the diagram, and it should be traced with special care. The line is now grounded through the tongue *t'* and lever of T' on the right; and the only current on the wire is from the battery at the other end. At the terminal where T' is there is no current on the artificial line, and the current of 20 ma on the main line closes the relay D' R'. But at the other terminal, where T is, the current in the coils of the artificial line neutralizes the current on the main line, and the relay D R opens; in other words, it obeys transmitter T'.

Lastly, when both transmitters are open. The battery at each terminal is off; there is no current in either the main or artificial line at either terminal, and the relays stand open. In this way are verified the results set down in the table; the relay in each case is unresponsive to the home instrument, but responsive to the distant transmitter; and signalling in opposite directions at the same time is practicable.

In explanation of the part played by the condenser in the long distance duplex, it may be said that when current flows in a wire, a portion of it collects and becomes static on the conducting material; and it will discharge instantly in any direction a path offers. In duplex work, the transmitter makes a line contact first with the battery, then with the ground; the conditions are present for a static charge and discharge of the wire; and the extent to which it is capable of these effects is called its electro-static capacity. On short lines it is small; so that, in the duplexing of such wires, the 'kick' is not noticeable; but there is a difference between a main line wire 450 miles in length, and the fine wire with which the coils of the rheostat are wound. So far as *resistance* to the current is concerned, the coils in the box are capable of reproducing exactly the conditions on the wire; but the main line wire has electro-static capacity; the fine wire of the rheostat coils has not. The initial charge in the line, therefore, will not, unless the condenser is used, be offset by an opposite movement in the artificial line; nor, at the termination of the signal, when the line is moved from the battery to the ground, will the discharge be offset by an opposite movement in the artificial line. A form of duplex was invented in Germany, and known in America as early as 1855; but it was worked only on comparatively short lines. The duplexing of long lines by the aid of the condenser was made practical in 1872; and the credit is due to Joseph B. Stearns of Boston. His was one of the notable achievements in the history of telegraphy, for by means of it the value of most of the wires of the telegraph companies was doubled at a stroke.

In the diagram, Fig. 24, there is indicated a connection from each transmitter through a coil *c r* to the ground at *b*. Before leaving the subject of the Stearns duplex, it is proposed to make a change in this circuit, and note results with a view to future reference and use. In each circuit move the wire from the point *b* to the point *b′*. When the transmitters are closed the *c r* circuits are open, so that the change to *b′* makes no difference on the line; but when a transmitter is open, the line has in circuit about one-third of the battery before it reaches the ground. Under these conditions, instead of the main and artificial lines being free of current, there would be on the main line coils in each relay, say 16 ma of current; and opposed to it in the artificial line coils about 8 ma. The difference (8 ma) would be sufficient to close the relays; but, according to the four-phase table, when the transmitters are open the relays should be open. Under these conditions, to open the relays it would be necessary to increase the tension on the armature spring. Now, if for any reason, we wish to maintain a weak current always on the line we could use for the purpose a portion of the bàttery, and counteract the effects of it by giving the spring *sp* sufficient tension to overcome the magnetism induced by the weak current; or, as the operators express it, the relay can be "turned up" above the weak current. This done, the operation of the duplex can be carried on as usual; the only difference is that the springs of the relays have tension sufficient to make them unresponsive to the weak currents. It is possible, therefore, to work a duplex of the Stearns pattern when the connections are such that the movement of each transmitter sends alternately to the line the whole battery and only one-third of it. This statement made, let us leave it for the present. It will be fitted into its place later, when we come to deal with the quadruplex in connection with which the statement just made plays an important part.

It remains only to gather up the terms and phrases used in describing the duplex; from this time on they must be a part of our vocabulary. We have had to do with the differential winding of a single core, the differential relay, main line, artificial line, rheostat, compensating resistance, transmitter, condenser, retardation coils marked *r r*, internal resistance (usually of a battery), the split, the balance, tension (of a spring), the static and its kick, charge and discharge, electrostatic capacity. If the reader will note in the diagram, as far as possible, each object named, he should get a better idea of its theory and function than could be obtained from a definition.

It thus appears that the characteristic instrument of the Stearns duplex is a relay, in appearance not very different from the ordinary relay of the single-line type; it can be constructed from it by a change in the winding from the simple to the differential form as represented in the diagram, Fig. 24. For the sake of simplicity all the thumbscrew connections, the front and back stop, and apparatus of the local circuit are omitted from the drawing; only the essential parts—the differential coils with the armature and spring—are shown. It will be noticed that the main line has a number of turns around one core, then around the other; the same with the artificial line. In practice, the points where the main and artificial lines enter and leave the instrument are fitted with four thumbscrews; two more are provided for the local points—one making connection with the armature, and the other with the front stop—forming parts of a local circuit as in the ordinary single-line relay. These omitted parts will be supplied in Fig. 29; but in dealing with first principles the fewer the details the better.

The Polar Duplex. In the same manner as we took the single-line relay and changed it to one of the differential type, so now it is proposed to take the latter, to make some changes in its construction; and, with a view to one more advance, to introduce a different form of armature and note the results. The yoke which, in the working instrument, joins the cores at the ends furthest from the armature is supposed to be removed; next take away the armature and turn end to end the cores that faced it, so that the coils, instead of lying parallel, are in a straight line. With a space of one-quarter or one-third inch between them they will present the appearance shown in Fig. 25, in which C and Z, C′ and Z′ represent the terminals of the coils; one core is marked D A, the other B E; and for observation the student is supposed to take up a position in the space between the cores. First, a current in the wire C Z encircles the core D A in a direction opposite to that of the hands of a clock, that is, from right to left, then it encircles the core B E in the direction of the hands of a clock, that is from left to right. If the student will imagine himself in place between the letters A and B he can readily understand this.

Heretofore we have been content merely to state the fact of the attraction of a magnet for its armature; the point has now been reached where it is necessary to state the law of the formation of magnetic poles in cores around which a current is passing. In "Elements of Electricity" are shown magnets marked N and S; in the text relating to the same it is explained that N stands for north-seeking, S for south-seeking; and there is further stated the law that like poles repel, while unlike poles attract, each other. Reverting now to what was said of the passing of a current round a core, let us, for the sake of brevity, call the directions just mentioned anti-clockwise and clockwise. At the end of the core, at which one is looking "end on", magnetic poles are formed according to this law: When the current passes anti-clockwise N polarity is induced in the near end, S polarity in the far end; when the current passes clockwise, S polarity is induced in the near end, N polarity in the far end. In the instance shown in Fig. 25 in the line C Z, there will be formed at A and D, N and S poles respectively; at B and E, S and N poles respectively. There is therefore on one side of the space between the cores an N magnetic pole; on the other side an S pole; it remains to provide something on which they may act.

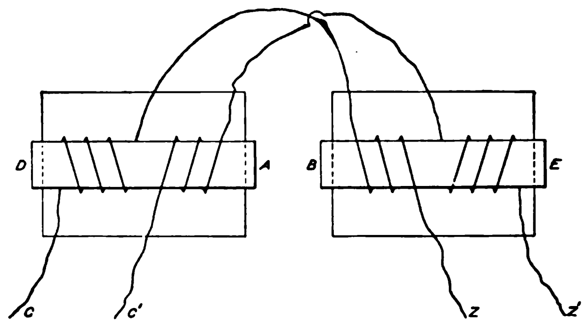


Fig. 25.

In Fig. 26 let S be the end of a permanent magnet semicircular in shape; a strip of soft iron for an armature is so pivoted that it can move freely between the stops at the upper end. In the armature the induced poles are marked with the small letters *n* and *s*, in accordance with the principle stated in "Elements of Electricity". With no current in the wire C′Z′, a current in the wire in the direction C to Z will induce, according to the clock rule, at A, N magnetism; at B, S magnetism. The N pole, according to a law already stated, attracts the *s* pole of the armature; the S pole repels it; the armature is strongly moved towards front stop F. The current ceases, let us suppose; but the armature has no spring, and its position remains unchanged until a current flows through the same wire in a direction from Z to C. Under its influence there is formed at B, an N pole; at A, a S pole; the effect on the *s* pole of the armature is to move it from the front to the back stop. Every time the current changes its direction the armature changes its position from one stop to another; and we have a *polar* relay. It is one in which a magnetized armature is moved from point to point under the influence of magnetic poles changing as the effect of changes in the direction of the current around the cores.

One step more and we have a *differential* polar relay. In the diagram, Fig. 26 is an extra wire with a number of turns around each core. Its terminals are C′ Z′; but it is so wound that a current from C′ to Z′ passes round the cores in a direction different from that in the line C to Z. The current from C′ passes first

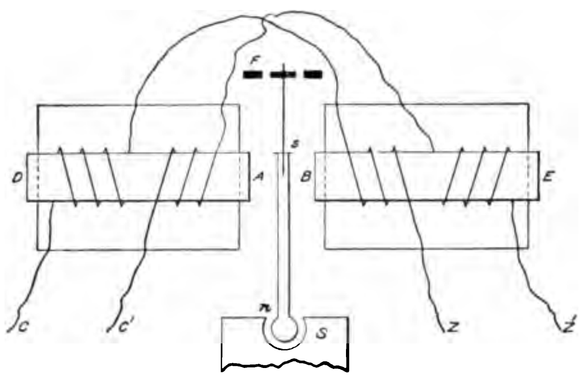


Fig. 26.

clockwise, then anti-clockwise around the cores; and from what has been said it is plain that if currents of equal strength flow in the wires C Z and C′ Z′ they will induce at A and B magnetic poles such that they will neutralize each other; provided, of course, there is the same number of turns in each coil. The effect on the armature will, in that case, be nil. But if the currents in C Z and C′ Z′ are not equal, the armature will obey the stronger current with a pull determined by the difference between the two. The result is a differential polar relay, by means of which that very perfect system of signalling in opposite directions—the polar duplex—is possible. The relay is made in different forms, but it consists essentially of a permanent magnet in which is pivoted a strip or tube of soft iron called the armature. This is placed between two cores around which are wound, in the manner shown i two independent circuits. The windings terminate in four thumbscrews, with two more for the local points, making six thumbscrews for the polar relay. The spools may be wound in various ways;

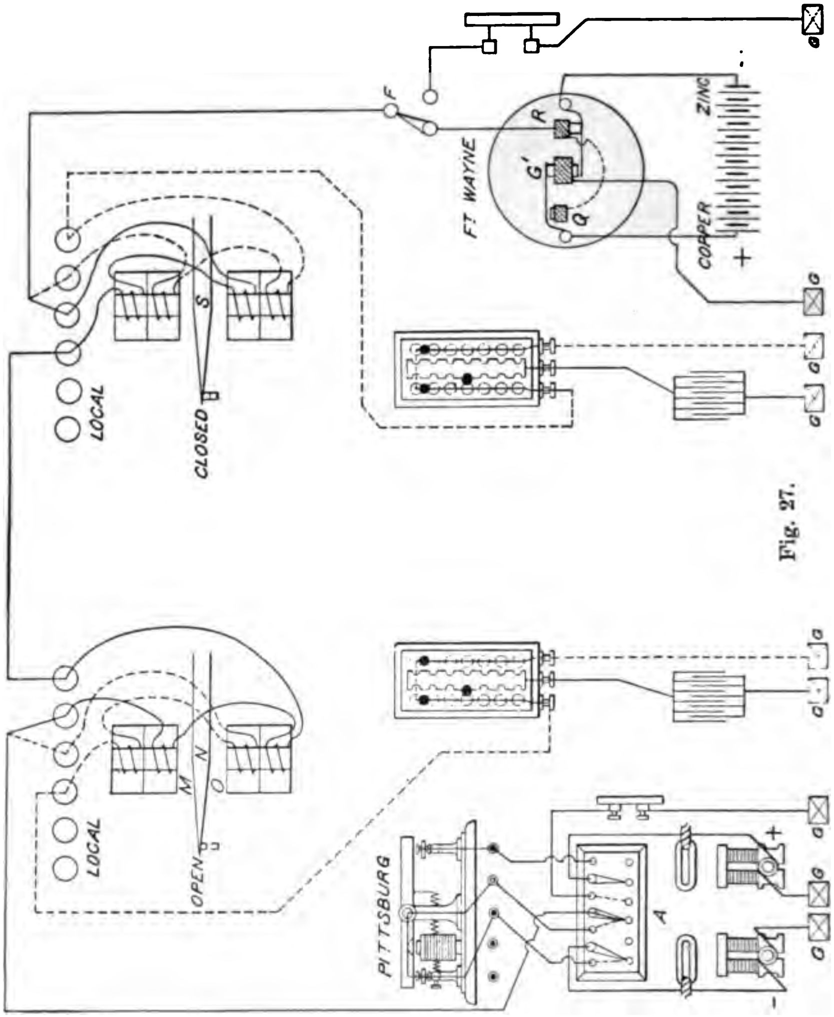


Fig. 27.

the wires may be laid side by side throughout the length of each core; or, as in the diagram, Fig. 27, in equal compartments separated by discs at right angles to the core. In the relays most commonly used each division of a spool contains 2,400 turns of wire, and has a resistance of 200 ohms; so that, in each circuit there is in the relay coils, a resistance of 400 ohms. This is equal to 42 miles (very nearly) of No. 6 iron wire, such as is commonly used in the construction of telegraph lines.

A differential polar relay, then, is one whose armature, polarized by contact with a permanent magnet, is operated by the difference in the strength of the currents, the direction of whose course is constantly being changed.

The instrument by which the direction of the current is reversed at will is called a *pole changer*, which, with the polar relay, the dynamos, lamps, and dynamo switch connected up, is shown in Fig. 27. These, with the rheostat and condenser described in connection with the Stearns apparatus, form a duplex set for one terminal. There is shown in the drawing one set for each terminal, and, for convenience in description, the left-hand station is called Pittsburg; the other Fort Wayne. The latter, as compared with the former, shows a different arrangement of battery and pole changer, of which explanation will be made later on. The Pittsburg pole changer is operated by means of electromagnets. These are part of a local circuit (not shown) and controlled by a key in the same way as the sounder in the learner's outfit. To the end posts of the pole changer are connected wires from dynamos supplying, let us suppose, a 200-volt current. It is made to pass through lamps and a switch; negative to the left, positive to the right. To the center lever of the switch is connected the main line. With the center bar of the switch to the left, connection is made with the lever of the pole changer, so that when the latter is closed a zinc current goes to the main line; when open, copper.

The lamps are placed between the dynamo and pole changer so that in case of a short circuit, by the lever of the pole changer accidentally making contact with both posts, a resistance of 1,200 ohms will be interposed until the short circuit can be broken and thus injury to the dynamo is prevented. The purpose of the dynamo switch is to provide means for readily cutting off the currents from the pole changer when any cleaning of the points or adjustment is required, or in case of a short circuit through the lever. With the center bar of switch A turned to the right, the main line goes to the ground through a resistance equal to that of each lamp, or 600 ohms; it makes no difference, therefore, in the *resistance* of the main line whether the center bar is to the left or to the right. From the switch the wire may be traced to the 'split' near the polar relay. At this point, as in the Stearns duplex, the current divides; one-half of the Pittsburg battery passing through two coils to the main line; the other half also through two coils to the rheostat, thence to the ground. The function of the rheostat, and its companion, the condenser, was explained in connection with the Stearns duplex; and it might be well to review that part of the text.

How to Balance. First approximate the balance by pegging or unpegging the rheostat to about 5,000 ohms for a line 450 miles long; in wet weather two-thirds of that. Ask the distant station—in this case, Fort Wayne—to ground; ground also at Pittsburg—the home station. Adjust, by means of the set screws, the armature of the polar relay so that it remains on one stop or the other as placed, or else vibrates freely under the influence of the slight current which the nearness of other wires on the poles may induce. Turn the switch from the ground to the pole changer connection. There is now on the wire no current of any account but your own; and the rheostat must now be so adjusted that the current from the home battery—in this case the Pittsburg —divides equally between the main and artificial lines. When it does this the armature of the home relay will vibrate freely as before.

In other words, the home current has no effect on the armature and the relay stands ready to respond to the current from the distant, or Fort Wayne, battery. Tell him to "cut in"; he does this by moving the lever of switch F from the right to the left-hand lower point; and when his key is closed your relay should close. Now, if you open and close your pole changer by means of your key the static "kick" will probably be noticed; and the remedy for it is the same as that described in connection with the Stearns duplex. This done, the "kick" disappears; the distant station writes, and it will be found that the signals sent from the home station by reversing the pole changer do not interfere with the incoming signals. Fort Wayne then asks you to ground and proceeds to balance his end; the duplex is then ready for service. In the hands of experts the operation of balancing both ways does not ordinarily require more than three minutes.

The right hand, or Fort Wayne, terminal shows an arrangement of battery and pole changer in vogue for many years before the use of the dynamo current in telegraphy; and it still obtains in a few places where a machine current is not available. The diagram represents the combination of a chemical battery of say 150 cells and the old-fashioned continuity-preserving, or clock-face, pole changer. The latter is retained here and described because it is also as an essential part of the phonoplex—the topic with which this book deals last.

In the diagram only the clock-face portion is shown; the part G′, in the center, represents the end of a lever operated like that shown in the Pittsburg pole changer, making contact with the ground. The poles of the battery connect with two springs as shown; the latter with the point-bearing blocks, Q and R are suitably insulated from the supporting material which is usually of brass. Q and R are connected to each other and to the main line. The connections made when the lever is closed are shown in the diagram. The left-hand spring is grounded, lifting it up from Q; the right-hand spring is free from the ground, but is making contact between the line and the zinc pole of the battery. When the pole changer is open, the center block drops down; the line makes connection with copper; zinc goes to the ground. In both forms of pole changer the results are therefore the same—zinc to the line when closed; copper when open—and this is the rule for their arrangement in practice. Care must evidently be taken for the adjustment of the pole changer in either form. "Clean and close" is the rule for placing of the points—as close, that is, as they can be worked without short-circuiting and sparking. Of pole changers and sounders alike the armatures must not be allowed to beat upon the magnets; to make sure they do not, a piece of paper should at times be passed between them.

As in the Stearns duplex, the polar duplex in operation has combinations of current four in number; and a description of the latter will not be complete without giving in detail the reason for the response of the relays in each combination. In advanced telegraphy there is no instrument in more general use than the polar relay; the principles involved are everywhere used; and a thorough understanding of them is neces astery of the more complex forms of apparatus and their latest applications. The changes in magnetic poles, as the result of changes in the direction of the current, will occupy our attention now; but before entering upon this we must consider the conditions which determine the direction of the current.

Much has been said about positive and negative currents, and the signs + and — are conventionally used to represent them; but these terms are not meant to convey the idea of strong and weak; a negative current may be strong or weak the same as a positive. In surveying it is convenient to consider "sea level" as a zero point from which to measure heights or depths, so in electrical potential the earth is taken as a neutral point and arbitrarily called zero; a current flowing into it is called positive; a current flowing from it, negative. If this seems unsatisfactory, perhaps an analogy may help us. Suppose we regard the air at rest as zero. Confine a rotating fan within a closed iron frame with a single tubular opening. Revolve the fan and, at the opening, a pressure will at once be felt of say 50 pounds to the inch. A few feet away the pressure will be 25; further away 15; and so on until no disturbance of the air is felt; the pressure is practically zero. Reverse the direction of the fan's motion so that instead of pressure outward there is suction inward, and at like distances effects like those just mentioned will be felt, but in an opposite sense. At the opening the suction is 50; whereas before there was an outward pressure of 50. In the one case we have the air at rest, the pressure, and the suction; these have their electrical analogies in the earth considered as zero potential; the positive current, which always sets towards the earth; and the negative, which always sets from it. The common direction of a thunderbolt is from a cloud to the earth, in this case the cloud must be positively charged; but instances have occurred where the direction of the bolt was from the earth to the cloud; in which case the cloud was negatively charged. In other words, and for the present purpose, the direction of the current is always + to zero, + to —, and zero to —; or, as stated, always from the higher potential to the lower. It is taken for granted that the same amount of current is supplied to the line at each terminal; in a duplex circuit 400 or 450 miles in length this is generally 150 or 200 volts. With these statements in mind the investigation of the combinations possible in duplex telegraphy may be taken up.

	Pgh key.	To line.	FtW relay.	FtW key.	To line.	Pgh relay.
1	Closed	—	Closed	Closed	—	Closed
2	Open	+	Open	Closed	—	Closed
3	Closed	—	Closed	Open	+	Open
4	Open	+	Open	Open	+	Open

In phases 1 and 4, the two stations present like poles to the main line; in phases 2 and 3 unlike poles.

Combination, or phase 1. Pole changers at terminals closed; zinc to the main line. In the diagram, the main line is solid black; the artificial line is dotted. With like poles of equal strength to the main line there is no current on the solid black line. Under these conditions on the artificial (dotted) line a current sets in from the ground through the rheostat, along the dotted line, through the pole changer to the zinc (—) of the dynamo in accordance with the law just stated. In the Pittsburg relay it forms first an N magnetic pole on the end of the core at M; then an S pole at O. If we enclose an N thus $\overline{\underline{N}}$ to represent the polarity of the Pittsburg armature, the magnetic conditions may be graphically represented: $\frac{n}{\overline{\underline{N}}}\atop s$ closing the relay in accordance with the law that like poles repel, unlike poles attract each other. Similarly, at the Fort Wayne end, by means of a current from the ground to the zinc of the battery the magnetic conditions are: $s \atop {\overline{\underline{S}} \atop n}$ also closing the relay.

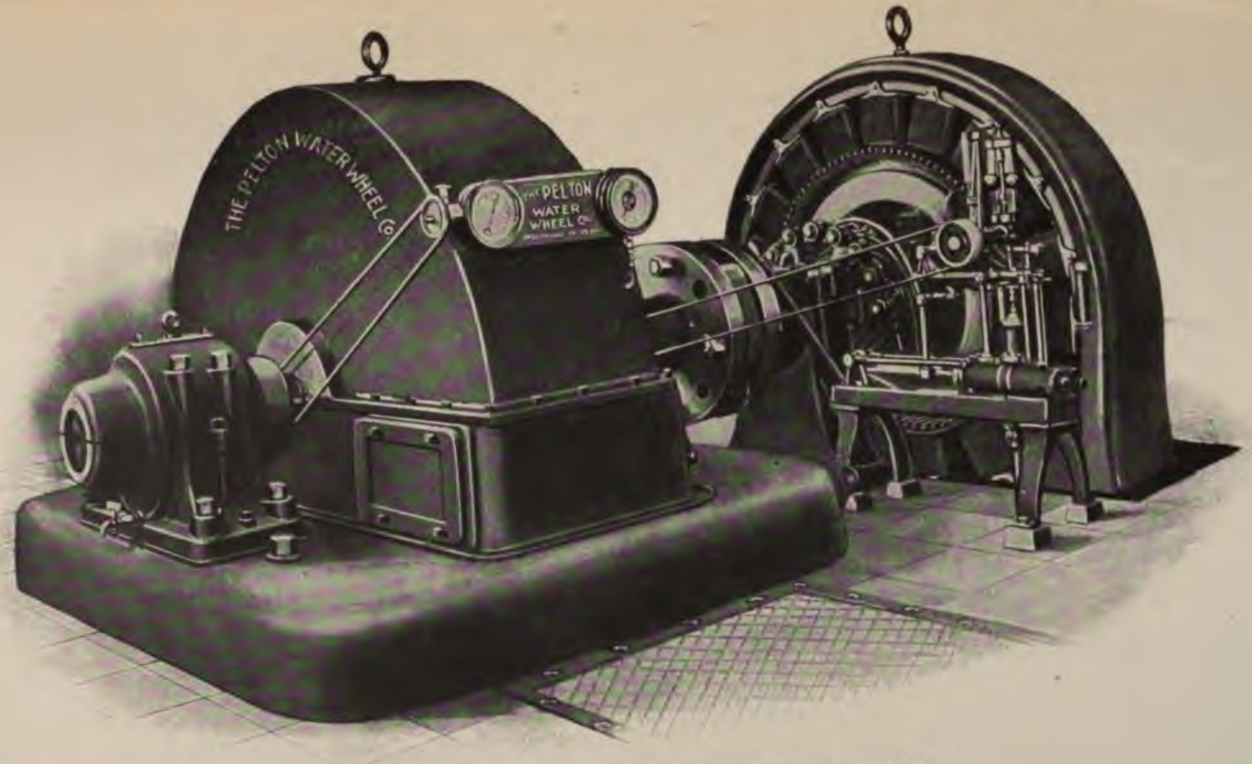
Combination 2 shows Pittsburg +, Fort Wayne — to line; current direction on the main line is from Pittsburg to Fort Wayne. On Pittsburg artificial (dotted) line, current is from + to ground through the rheostat; on Fort Wayne artificial line it is from ground through the rheostat to — of the battery, the same as in combination 1. But the current on the main line is twice that on either of the artificia' lines; because in the former case the current is from + to ... ter case it is from + to ground at one term ... — at the other.

The magnetic poles induced in the cores by the current on the main line are therefore twice as strong as those induced in the cores by the current on the artificial line. If we represent the magnetism induced by the main line current by a capital, and that induced by the artificial line current by a small letter, and indicate the polarity of the armature as before, the magnetic conditions in the Pittsburg relay may be typographically represented thus: $\begin{array}{c} Ns \\ \overline{N} \\ \overline{nS} \end{array}$ the stronger poles closing the relay; in the Fort Wayne relay $\begin{array}{c} Ns \\ \overline{S} \\ \overline{Sn} \end{array}$ the stronger poles opening the relay.

Combination 3. Pittsburg — to line; Fort Wayne + to line. Current in opposite direction to that in combination 2; but on main line twice as strong as on either artificial line; in the Pittsburg relay the conditions are $\begin{array}{c} Sn \\ \overline{N} \\ \overline{Ns} \end{array}$ opening it; in the Fort Wayne relay $\begin{array}{c} Sn \\ \overline{S} \\ Ns \end{array}$ closing it.

Combination 4. + to the main line at each end; no current on the main line; relays actuated as in combination 1 by current in artificial line; in Pittsburg relay $\begin{array}{c} s \\ \overline{N} \\ \overline{n} \end{array}$ opening it; in Fort Wayne relay $\begin{array}{c} n \\ \overline{S} \\ \overline{s} \end{array}$ also opening it. The Fort Wayne relay might have an N armature the same as Pittsburg, but it was purposely made different to afford exercise in tracing out the effect of the current.

The student should now be master of at least the theory of the two forms of the duplex—the original Stearns and the later and more perfect polar. The former came into general use in 1872, the latter about 1880. In making comparison between the two it can be seen that the superiority of the polar duplex lies in the



3,000 H.P. PELTON WHEEL AND 1,500 K.W. GENERATOR.

Example of Iron-Mounted Construction.

relay whose action is determined, not, as in the Stearns, by a current attracting the armature in one direction and a spring drawing it in the other, but by a current directing its movement first to the front then to the back stop. This makes the polar duplex almost independent of weather conditions. The occasions are rare, the relay being so sensitive, when sufficient current does not get past the escape to record the signals. The resistance of 450 or 500 miles of No. 6 gauge iron wire is, in dry weather, about 5,000 ohms; in damp or rainy weather this is often reduced to two-thirds, or even one-half. This is a good point to remember in adjusting the rheostat to get into communication initially with a distant station before the correct balance is taken. Less condenser, also, is needed in moist weather than in dry, because a part, sometimes nearly all, of the static charge escapes into the moist air.

With a clear wire and apparatus in good condition, the polar duplex is a well-nigh perfect instrument capable of a speed, when working the Morse system, equal to that of the fastest typewriter; and when operated by the Wheatstone Automatic system it has attained a speed of 250 words a minute each way—nearly ten times as fast as the ordinary speed by hand.

THE QUADRUPLEX.

The quadruplex—among telegraphers known always as the quad—permits the exchange of four messages at the same time; two in each direction. In the diagram, Fig. 28, presenting the theory of the quad, there is much that will seem familiar to the student; the text has been so arranged and the drawings so made as to give the impression of previous acquaintance. The neutral relays are a reproduction of the instruments made prominent in the Stearns duplex; the polar relays are those which we have just studied in the polar duplex. The rheostats—the same in principle as those already shown—are represented by a simple coil; and, shunting each, is the now familiar condenser, H and J, each with its retardation coil *Rc*. The batteries and pole changers are a reproduction of those shown in connection with the polar duplex.

At the left hand, or Pittsburg, end the dynamo switch has been omitted for the sake of simplicity; everything, in fact, has been left out except the parts needed to illustrate the fundamental principles on which the quad is arranged. The details which make the quad appear so complicated can be filled in later. In the diagram the one new feature is the introduction at each end of

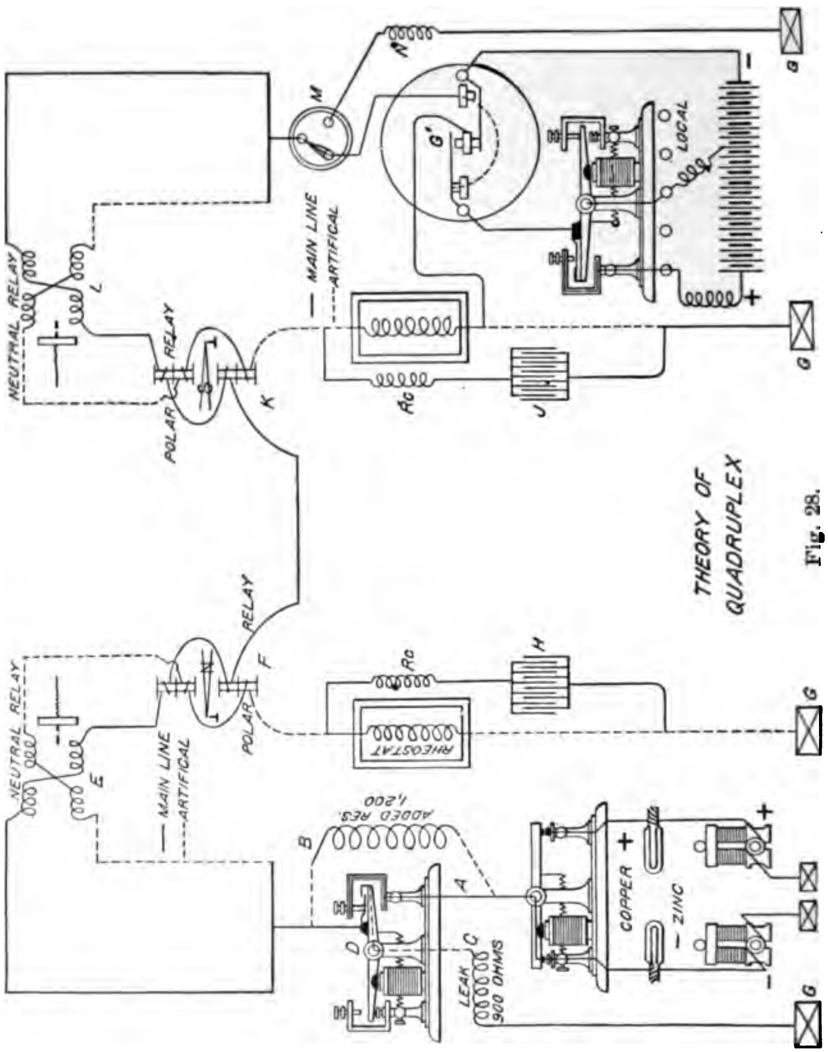


Fig. 28.

a transmitter in combination with the pole changer; at the Pittsburg end it is between the pole changer and the split; at the Fort Wayne end between the battery and the pole changer.

We have seen that it is the function of the pole changer to alter the *direction* of the current; it is the function of a transmitter, like those shown in Fig. 28, to alter the *strength* of the current within certain well-defined limits. Now the pole changers are evidently in position for the purpose of operating the polar relays; the transmitters can therefore be in place only to operate the neutral relays. The instruments heretofore designated as polar and neutral are also called polar and common; the sides on which they are worked are sometimes called by the numbers 1 and 2, and sometimes by the letters A and B.

From what has been said, the student may already have inferred that a neutral relay is one operated by the strength of the current without reference to its direction; he knows that a polar relay is operated by the direction of the current without reference, within reasonable limits, to its strength; and *in the combination of these two principles* lies the theory of the quad, as it is commonly known. There are other forms of the quad; but our present business is with the one still in general use.

The student is now asked to recall and review an experiment made in connection with the Stearns duplex, and intended for introduction at this point. It was made clear that, by the simple expedient of "turning up" on the relay spring, the Stearns duplex could be operated even when a weak current remained continuously on the main line; or, as it was expressed in a former paragraph, "If, for any reason, we desired to maintain a weak current on the line, we could use therefor a portion of the battery and counteract the effects of the weak portion by giving the spring sufficient tension to overcome the magnetism induced by it." The need has now arisen for maintaining at least a portion of the current continuously on the line; and the reason for it is that changes in the direction of a comparatively weak current will operate a polar relay as readily as the reversals of a current three or four times as strong. The neutral relay can be made unresponsive to the weak current, but responsive to a strong current without reference to its direction; in other words, the quadruple is merely a combination of the Stearns duplex, in a form modified as shown in the text, with the polar duplex. It remains only to explain so ination.

the direction of the current is changed it is plain there must be a very brief moment of time when there is no current on the line; at such moments there is a tendency on the part of the armature of the neutral relay to fall away from the magnets. If the local contact were on the front stop this would record a false signal: and the greater the length of the wire worked in the quad the more apparent is the interval.

On all long-distance quads, with a view to eliminate the false signal, there is interposed (see Fig. 29) between the relay and the recording sounder, what is called a repeating sounder; the device however, is not an entire success, and the signals on the common side lack firmness to an extent which affects the speed.

Troubles of the Quad. It is usual in text books dealing with this subject to devote considerable space to the troubles of the quad. An expert quad man is not he who sets up quadruplexes—that is generally done by the office lineman—it is one who keeps the quad in working shape, and who, when any stoppage or defect arises, can locate the trouble and remove it. In the language of the craft, a defect in the set is called a "bug"; and those who deal with them are known as "bug hunters." It would be possible to fill a book the size of this with the ailments of the quad; how to locate and remedy them; the reader might study it attentively, but if his knowledge of the principles underlying the quad arrangement was hazy he might, and probably would, be worsted by the very first trouble he met; on the other hand, if he is thoroughly versed, as it has been the aim in these pages to make him, in first principles, each experience of trouble and its removal will prepare him to cope with the one that next presents itself. A prime qualification for anyone who aspires to be a defect hunter is a persistence in the search which never flags until the root of the trouble has been found and removed.

A very insidious defect in a quad, because, slight at first, it may gradually grow worse, is that of unevenness in the coils, producing what is called a "lop-sided" relay. It is well to make tests, at stated times, of the relay coils with a current other than that of the quad. It need hardly be said that the batteries for the quad must be kept up to the standard; that the ground wires and their resistance coils, which are a part of the circuit when a balthe upper core S polarity; in the lower N; the effect of these on the S armature is to close it; the effect of the transmitter closed at Pittsburg is to close the Fort Wayne neutral relay. The number of phases or combinations possible to the eight instruments (four at each end) of the quad is sixteen; and one of these has been traced out with the results described. The general result in every case is that the Fort Wayne neutral relay obeys the Pittsburg transmitter; the Fort Wayne polar relay obeys the Pittsburg pole changer, and *vice versa*.

How to Balance. The operation of balancing the quad is the same as that followed in connection with the polar duplex, except that the static is eliminated by watching its effect on the neutral relay instead of the polar. Approximate the resistance in the rheostat to that of the main line: Pittsburg then asks Fort Wayne for his ground, and goes on the ground himself. Center the relay so that the armature remains on the front or back stop as placed; or vibrates freely under the influence of slight extraneous currents. Turn on the home, or Pittsburg, battery and adjust the rheostat until the polar relay vibrates freely as before. Now wedge the sounder of the polar relay in order to silence it temporarily. Turn down on the spring of the neutral relay; close the transmitter and dot slowly on the pole changer. Commonly a kick will be felt on the neutral relay which can be removed by adjusting the plugs on the condensers; turn down further on the spring and readjust the condensers; turn down still more if necessary and readjust the plugs until all trace of the kick is removed. Now restore the spring to its normal pull, and ask Fort Wayne to cut in. Ask him to write on the common, or No. 2, side and dot on the polar side. Pittsburg does the same, and, if his balance is correct, the signals from Fort Wayne on each side of the quad will be clear-cut and readable. Pittsburg now grounds for Fort Wayne, who goes through the same routine, and tests the result in the same way. This done, the quad is ready for service and is capable during a day of 9½ hours of carrying 300 messages each way on the polar side, and 250 each way on the common side.

The slower work on the No. 2 side has its source in a defect in the quad which has never been entirely overcome. In the operation of the pole changer, even of the clock-face kind, when gives fairly satisfactory results. In an office where two quad sets are available, and occasional cessation in their use gives opportunity, the following plan for familiarizing one's self with the quad and its troubles is suggested by an expert. Select a station 200 miles away and ask him to "loop", that is to join together, two wires which you name. Connect the two wires to adjacent sets in your own office. Balance them as though they were distant sets. Now introduce into one set any form of interference or disconnection that would be likely to occur in practice, and observe the effect on the other set; experience may be gained in this way that would aid in the location of trouble when it occurs in practice.

Duplex Repeater. In wires worked on the duplex or quadruplex system, the static capacity of the wire places a limit on the number of straight miles a circuit can be worked. But the distance between stations can be greatly extended by the use of repeaters in which, by a perfectly simple arrangement of local circuits, the pole changer of a second circuit is controlled by the relay points of the first, and *vice versa*. For example, in the text, a duplex Pittsburg to Fort Wayne was described; call it the first circuit. For a second circuit suppose Fort Wayne has a duplex to Chicago, and that Pittsburg wishes to be put through direct. By means of switch-jacks and cords provided for the purpose, Fort Wayne makes the electromagnets of the pole changer of his northern set a part of the local circuit which passes through the points of the polar relay of his Pittsburg, or eastern, set; he also makes the electromagnets of the pole changer of his eastern set a part of the local circuit which passes through the points of the polar relay of his northern set; Pittsburg and Chicago can then work duplex. The longest regular circuit in the United States is that worked between New York and San Francisco with six repeaters; another long circuit is that between New York and Heart's Content, Newfoundland, with repeaters at Boston, St. John, and North Sydney. In a few seconds these two circuits could be repeatered at New York; San Francisco and Heart's Content could then work duplex through nine repeaters—a circuit from ocean to ocean where the continent is widest.

The Repeating Sounder. *Duplex Loops.* Fig. 29 shows the local connections of the common side of a quad and the method of

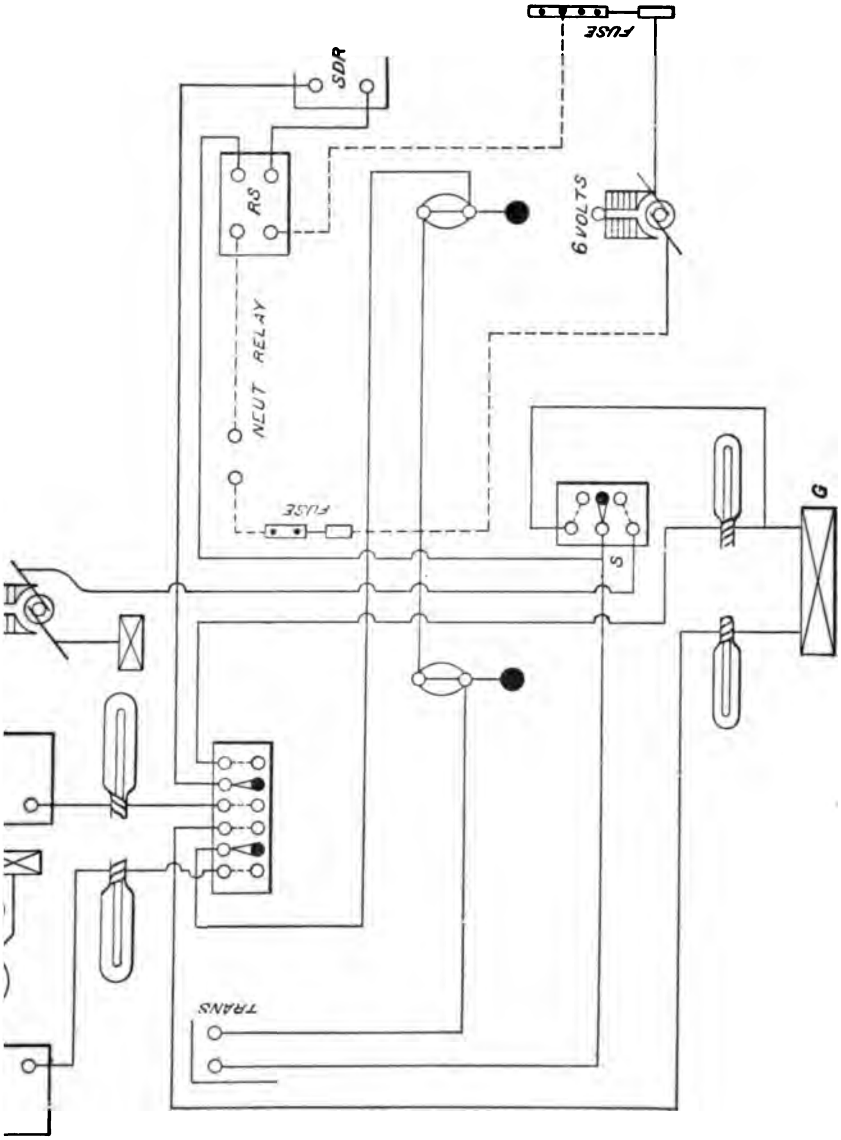


Fig. 29.

current supply which, it is seen, is from two independent sources. The common side is shown preferably because it exhibits, in place, the repeating sounder, to which reference was made in a preceding paragraph, in the receiving, or relay, side. The current supply is a 6-volt dynamo, from one pole of which a wire extends through a fuse to the armature of the neutral relay. From the *back*, not the front, stop of the relay it passes through the coils of the repeating sounder, through another fuse, back to the dynamo, thus completing a metallic circuit. When the neutral relay is on the front stop, the *repeating* sounder is open; but its points, between the lever and the up stop, are closed, permitting the 23-volt current to close the other sounder from which the signals are read. When the neutral relay points open, the repeating sounder is closed, but the receiving sounder is open; the reason for this arrangement has already been given in the text on the quad.

The regular local system of a duplex, or one side of a quadruplex, is not a metallic circuit; it is a grounded system supplied, as the drawing shows, by a 23-volt dynamo. The reason for the ground arrangement is that in all the principal offices by far the greater number of the duplex and quadruplex sets are fitted up so that while the sets themselves are in the main office, where they can receive expert attention, they can be operated in branch offices by means of what are called "loops", or "legs". By suitable switches the loops can be cut in or out as desired.

The current from the 23-volt dynamo runs first to a fuse block (not shown); thence to a small 3-point switch, the lever of which, if turned to the left, connects the battery with the set; if turned to the right it connects the set with the ground. The latter connection is made in "setting up" a duplex repeater. With the lever to the left, the current is seen in the drawing to divide at the point S; one branch can be traced through the points of the repeating sounder, through the coils of the receiving sounder; thence (with the lever of the 6-point switch to the right) through a lamp of about 96 ohms resistance to the ground. The other branch can be traced through the coils of the transmitter; through two keys; thence (the lever of the 6-point switch to the right) through a lamp to the ground. The purpose of the lamps is to make the resistance in the circuits the same in either position of the levers of the 6-

point switch. Above this switch are the connections and outfit of a branch office for the operation of a duplex; or, what is known as a duplex loop. It shows one wire connecting a lamp and the coils of a sounder to the ground; another wire connecting a lamp, sounder and key to the ground for the sending side; the first mentioned sounder is that of the receiving side. To cut them in, turn the levers of the 6-point switch to the left; the relay then operates a receiving sounder in both main and branch offices; the branch office can operate the transmitter and work duplex with another city or a branch office therein similarly equipped. The word "loop", though commonly used in this connection, is a misnomer. In telegraphy, loops connect an outlying office, which may be rods or miles away, with a single Morse circuit. To do this, the pair of wires leading to the distant relay, which makes the loop properly so called, terminates in a wedge which can be inserted in the spring-jack of any wire in the main switch. In the duplex arrangement the wires operating the branch instruments are merely extensions of the sending and receiving sides of the local system.

There are many matters of detail in connection with the setting-up and operation of a quad which do not properly fall within the scope of this work. For special works on the duplex and quadruplex the reader is referred to Thom and Jones' Telegraphic Connections; to Jones' Pocket Edition of Diagrams; and to Maver's American Telegraphy: Its Systems and Operation.

THE PHONOPLEX.

Among contrivances for increasing telegraphic facilities a worthy place is occupied by the device known as the Phonoplex—an invention of Mr. Thomas A. Edison. In its mode of operation it will be found to differ materially from anything heretofore presented; its essential feature being the superposition, without noticeable interference, of the high-tension impulses of a magnetic coil upon the current or currents of the Morse system. Even when all the wires on the route are crossed or grounded, not excepting the one upon which the phonoplex is working, it admits of serviceable operation.

It can be worked in connection with the duplex and quadruplex systems; but its usefulness is greatest as an adjunct to the single-line service of the railw in a sphere where

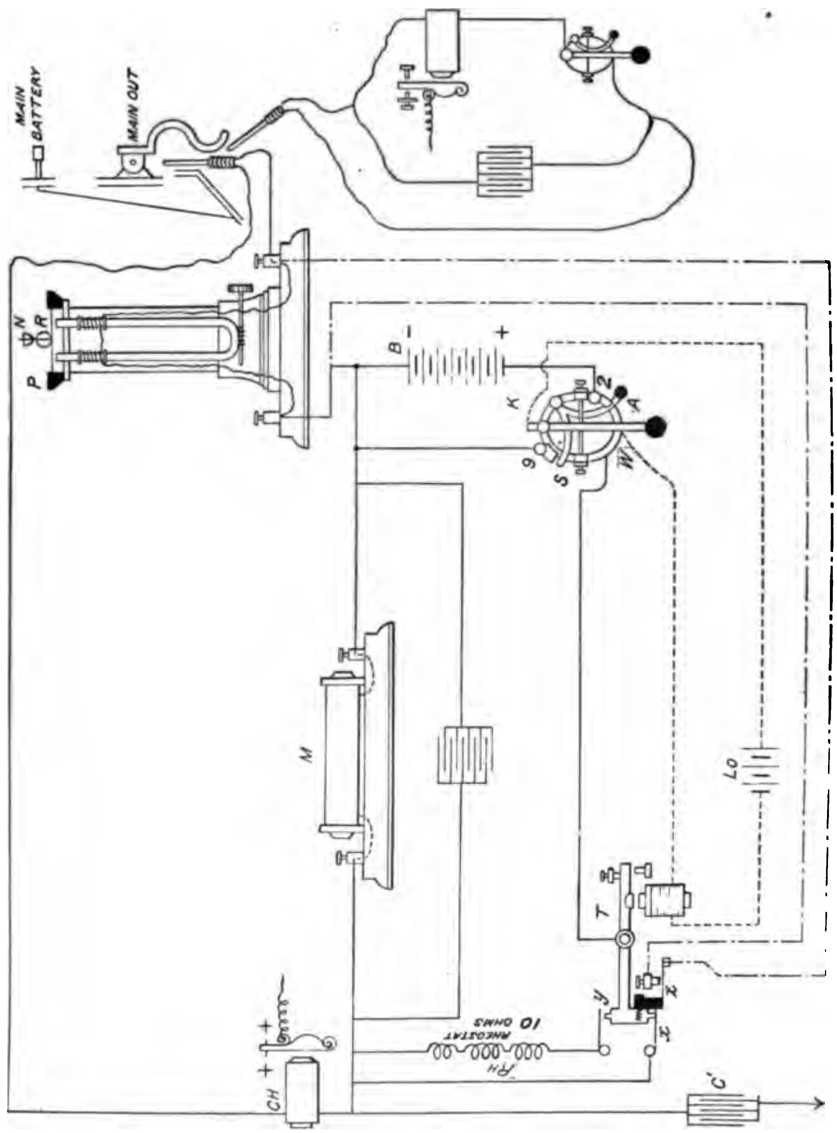


Fig. 30.

the number of wires is usually limited, an extra circuit which is at all times available. The apparatus is adapted for use between intermediate, as well as between terminal, points; but the diagram (Fig. 30) presents, and the text describes, the arrangement of a terminal station where the single wire takes its battery. As it embodies some new features, the details require more than usual length in their description. Referring now to the diagram—on the right is seen the spring-jack of a terminal switch, showing main battery and line connections. Two wedges are inserted in the jack; one carries the conductors to the phonoplex; the other cuts in a main-line key and relay which are bridged by condensers; the bridging arrangement obtains also at every intermediate station. This use of condensers makes feasible the operation of the phonoplex in the presence of crossed and grounded wires—a feature to which reference has already been made.

The phonoplex requires for its operation, two batteries—one, B, of at least five 2-volt cells, and one, *Lo*, of three cells; a key and transmitter, each of peculiar construction; a small rheostat containing five coils of two ohms each; a simple magnetic coil, bridged by a condenser of small capacity, to quicken the impulses sent out from the coil; an ordinary Morse relay and condenser; and, lastly, the characteristic phonoplex instrument itself, marked P in the diagram. The latter consists of a circular wood base supporting an upright cylinder containing an elongated horseshoe magnet, upon each pole of which is wound a small coil of insulated copper wire. Above the poles, and covering them, is a metallic diaphragm like that used in the telephone. A split steel ring R rests upon this diaphragm, or moves freely upon a threaded vertical pin N, at the top of which is placed an adjustable nut. Each agitation of the diaphragm causes the steel ring to be thrown up against the nut, producing an excellent imitation of the well-known "click" of the sounder. Between magnetic coil M and the main battery is an ordinary 150-ohm Morse relay C H, which acts as a choke-coil; to it is tapped a condenser C′, and a ground. *Rh* is a small adjustable resistance box containing five coils of about 2 ohms each. This resistance is introduced into one of the circuits bridging the magnetic coil, in order to weaken the current so that one stroke of the phone recorder may be distinguished from the other; otherwise the "back-stroke" effect would ensue, and the signals would not be readable. Of the wires bridging the magnetic coil two, on the left-hand side, terminate in springs between which moves the hammer-headed lever of the transmitter operated in the usual manner by means of local battery *Lo*, and key K. The lower end of the hammer-head also has an attachment which acts on spring *z* for a purpose which will be explained later.

It is difficult to represent in a diagram the insulated portions of key K; in order to understand its working a detailed description is necessary. The key and its attachments control two independent circuits. The ordinary circuit-closing switch is absent; the local circuit (dotted) is always "open" except when signals are being sent. One conductor of the local circuit makes connection with the anvil post W which is insulated from the base, and is fixed underneath the lever. To the further end of the lever is attached the other end of the local circuit conductor, so that when the key is depressed, the transmitter is closed. To the near end of the base of the key is connected a wire leading to the lever of the transmitter T. Attached to the base by means of a screw, which serves also as a pivot, is a curved arm A, at the pivoted end of which is a curved spur *s* reaching across the base of the key. At 2 and 9 are small spurred thumbscrews attached to, but insulated from the base; so that, in the position shown in the diagram, the arm A puts 2 in contact with the base; but if the arm is withdrawn from 2 a sufficient distance then 9 makes contact with the base through the spur *s*.

To understand the working of the apparatus it must be borne in mind that the transmitter, unlike that of the Stearns duplex, produces the effects of dots and dashes by the "breaks", and not by contacts. In the diagram, the lever of key K, and that of transmitter T are open; the current from B flows from + to 2, through the base of K and the lever of T, through spring *x* and the coil M, to – of battery MB, thereby charging the coil with the full strength of B. The act of depressing the key lever breaks the contact at *x*, coil M discharges, and a loud "snap" is heard in the distant phone or phones. When the lever T strikes the upper spring *y*, the current flows through *y* instead of *x*, thence through resistance R*h*, charging coil M less strongly than before; so that, when the upward movement, or opening, of the key breaks the contact at *y*, a less pronounced snap is heard on the distant phone; thus obviating, as already stated, the effect of the "back-stroke".

It will be noticed that, during this sending operation, the curved arm is to the right, which is the position of an ordinary key when an operator is sending. When he begins to receive on the phone, he moves the curved arm to the left, which movement corresponds to the "closing" of an ordinary key; but in this case the movement simply disconnects the battery B from the transmitter, and the spur *s* makes connection between 9 and the base, shunting the magnetic coil, so that the phone may be affected by the maximum of charge and discharge from the distant magnetic coil.

One feature remains to be described. Leading from the terminals of the phone may be noticed a shunt circuit (in dots and dashes) terminating in spring *z* and a contact point above. The position of spring *z* is such that when the transmitter is open and its lever in a downward position, the shunt circuit is open; but when the hammer end of lever T is raised, and so long as it remains so, the phone is shunted. This automatic shunting of the phone during the time when the lever is "breaking" the charging currents of the coil, obviates annoyance from the discharges of magnetic coil M to the operator who is sending in proximity to the home phone.

H.M.S. RUSSELL. LONG DISTANCE WIRELESS TELEGRAPH EQUIPMENT.

Marconi System.

The American Marconi Co. is Financed by [illegible]

WIRELESS TELEGRAPHY.*

HISTORY.

The practice of signaling through space may be traced back through the ages to the beginning of the history of mankind, for the earliest records indicate that the survival of the fittest sent powerful sounds from his lips through the air, and that for longer distances he employed fire to propagate light waves through the subtler medium of the ether.

As civilization advanced, the necessity of transmitting intelligence to a longer distance and with a broader interpretation, led to the introduction of many forms of intercommunication, made possible by the invention of writing and the use of semaphores, but these were not without their special limitations since the former consumed time in transportation and the latter could be operated only where a direct visual line between the sender and receiver was possible.

With the advent of experimental electricity and the knowledge of its properties for traversing long lengths of wire with practically the speed of light, came the burning desire to utilize it for the transmission of messages, but we need not here dwell upon the remarkable events that gave us the electric telegraph, the submarine cable and the speaking telephone, for these do not form a part of the subject herein treated; but instead we shall follow the evolution of that allied and newer branch of the art called *wireless telegraphy*.

For at least a century before an electric impulse, representing a signal, had actually been transmitted and received without intervening and connecting wires coupling the two opposite but complementary instruments, the subject was a favorite one with the physicist, and it is not unlikely that the ancient Greeks who witnessed Thale's experiment of transferring energy from electrified

* Prepared especially for the Cyclopedia of Ap
A. Frederick Collins, Author of "Wireless Telegraphy
and Practice."

amber to neutral paper, dreamed of the bridging of greater distances by the same mysterious influence.

The first recorded instance, however, in which a definite scheme was proposed having for its object the telegraphing without wires by electricity, was that given by Silva, a Spanish physicist, who read a paper "On the Application of Electricity to Telegraphy" before the Academy of Sciences on Dec. 16, 1795, at Barcelona. In this prophetic memoir, he advocated that a given area of earth be positively electrified at Mellorca and that a similar area of earth be charged to the opposite sign at Alicante; the sea connecting these two cities would then act as a conductor when the electric difference of potential would be restored, and by a proper translating device the transfer of energy could be indicated.

Conductivity Method. The first experiment resulting in the successful transmission of electricity between two points without an artificial connection may be ascribed with considerable certainty, to Steinheil of Bavaria, who made the important discovery that the earth could be utilized in place of the usual return conductor of a wire telegraph line. After ascertaining the fact that current traversing such a circuit flowed in innumerable curved lines between the terminals of the line wire embedded in the earth, Steinheil then found that by placing a similar pair of earth plates, 3, 3′ and 4, 4′, likewise connected together and having a galvanometer 5 interposed in the circuit, parallel with the first, which included a battery and a key 2, as shown in Fig. 1, there was a sufficient dispersion or leakage of the current from the one to affect the other to the extent of deflecting the needle of the galvanometer. The dotted lines represent currents in the earth.

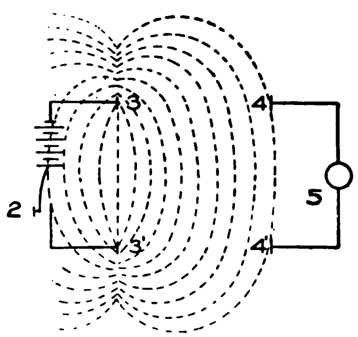


Fig. 1. Conductivity Method.

These pioneer experiments were made in 1838, the discoverer having proven it possible to obtain calculations at a distance of at least 50 feet, this forming the basis of what is now known as the *dispersion* or *conductivity* method of wireless telegraphy. This mode of transmission has been thoroughly tested by many investigators since its inception until 1892 when Preece, of England, obtained results from Lavernoch Point to Steepholm in the Bristol Channel, a distance of nearly five and a half miles.

The invention of the telephone receiver by Bell opened fresh fields in the realm of signaling through space, owing to its extraordinary sensitiveness; and by means of this remarkable instrument an effort was made to determine the inductive effects of telephone circuits. This was attempted in 1877, by Saches, of Austria, who arranged two parallel circuits, each forming a loop 120 meters in length with a distance of 20 meters separating them. A current from three cells was employed for exciting the first circuit, and this was found ample to produce distinctly audible signals in the telephone receiver.

Inductivity Method. Following these researches, Trowbridge, of Boston, carried on a large number of experiments in electromagnetic induction, the arrangement of which is illustrated in Fig. 2. In this method, two coils of wire 3 and 4, formed of many turns, are placed in parallel, or in a plane with each other; a battery and key 2 are connected in series with one coil and a telephone receiver 5 in the complementary loop of wire. When the coils are adjusted several yards apart, the "make and break" of the sending circuit by the key causes the electric energy to be transformed into curved magnetic lines which thread through the receiving coil producing in the latter an electromotive force proportional to the rate at which they link with it. Trowbridge believed that this *inductive method*, as it is termed, could be made to operate effectively between vessels separated by a distance of at least a mile.

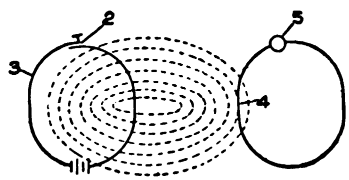
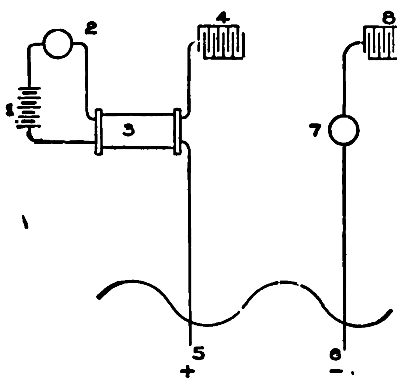


Fig. 2. Inductivity Method.

Electrostatic Method. A curious coincidence is now presented in the *electrostatic* method evolved (patented and experimented with by Dolbear, of Boston, in 1886) since it is an almost exact counterpart of that proposed by Silva in 1795, for the apparatus of the former is designed to fulfill the precise fı required by the hypothesis of the latter, that is, the charging of the earth at the sending and receiving stations to opposite signs. The sending instrument, indicated diagrammatically in Fig. 3, consisted of a small induction coil 3, the primary winding of which was connected with a battery 1, an interrupter, and a key 2, while the terminals of the secondary coil were connected with a condenser 4 and the earth 5, respectively; the receiver was formed of a condenser 10, one side being connected to a battery 9, which in turn



Electrostatic Method.

Fig. 3.

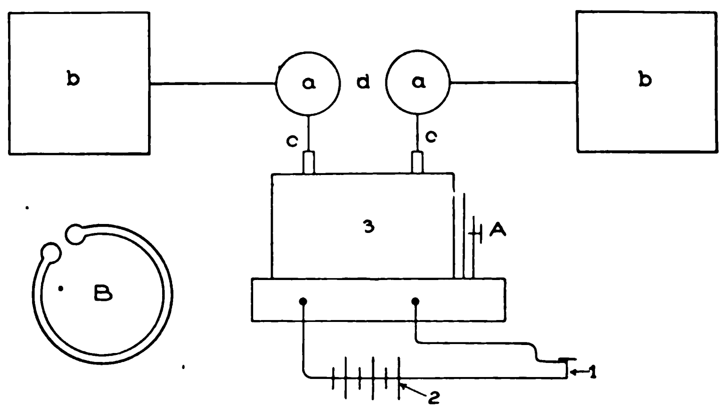
led to a second condenser 8, thence to a static telephone receiver 7, the terminal connecting to a plate 6 in the earth. Edison followed with a somewhat similar arrangement in 1891, except that he employed ærial wires with plates of metal at the top, which served as capacity areas, instead of the condensers described above. There is no authentic record of the performance of either of these devices.

Electric Wave Method. All the methods described above have their especial limitations, and these are so tightly drawn that none of them have ever approximated a utility of the slightest commercial importance; work, however, continued along these lines, but during the past fifty years an entirely new method has been unfolding, a method at once marvelous in conception, beautiful in theory, perfect in formation, and startling in its final results; this is the *electromagnetic wave method.*

The fundamental principles upon which this method is based may be said to have begun in 1678 when Huygens, a Dutch mathematician, conceived the hypothesis that all space not taken up by gross matter was filled with a highly attenuated subtle substance named ether, and by which he was enabled to account logically for all the phenomena of light.

Faraday, in 1845, not only believed in Huygen's luminiferous ether but demonstrated by experiment that electric and magnetic forces were propagated through the same medium. This physical evidence was resolved into a mighty theoretical system by Maxwell who determined mathematically the relations between all the varied phenomena presented by these different, yet allied, sciences.

The last link in the chain necessary to establish absolutely these great fundamental truths was supplied by Hertz, of Karlsruhe, Germany, in 1888, who succeeded in producing electromagnetic, or, as he termed them simply, electric waves, which followed every known law of light, such as rectilinear propagation, refraction, polarization, etc. The electric waves discovered by Hertz are, of course, much longer than those of light, and being much too long



Hertz's Electromagnetic Wave Method.

Fig. 4.

to affect the eye, they are invisible; every known test, however, only served to offer additional proof that the Hertzian waves are transverse vibrations in the ether, and that they are propagated through space at a velocity equal to that of light.

The apparatus Hertz employed in producing and receiving electric waves is shown in Fig. 4. The sending apparatus A comprises an induction coil 3 energized by a battery 2, and operated by a key 1; the high-tension terminals are connected to an oscillator formed of two brass spheres *a*, *a* attached to large metal sheets *b*, *b* by brass rods; this is the arrangement by which the waves were radiated. The spark-gap is shown at *d*. The receiver B is simply a loop of wire with the free ends brought nearly together, and when the waves impinged upon it, their presence was indicated by the passage of minute sparks in the gap formed between the ends.

Here then was a complete apparatus for fulfilling the conditions of signaling through space without wires; but many improvements were needed before an efficient system could be produced capable of operating on a commercial scale. For instance, the metal ring receiver of Hertz required too much energy to affect it at any great distance, but this defect was overcome by Branly, of Paris, who found,

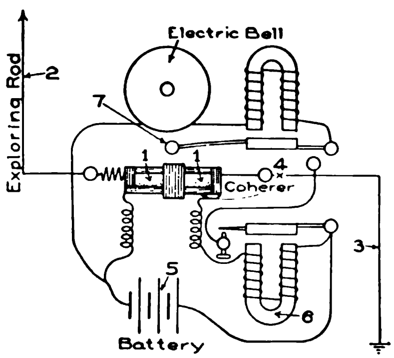


Fig. 5. Popoff's Receiver

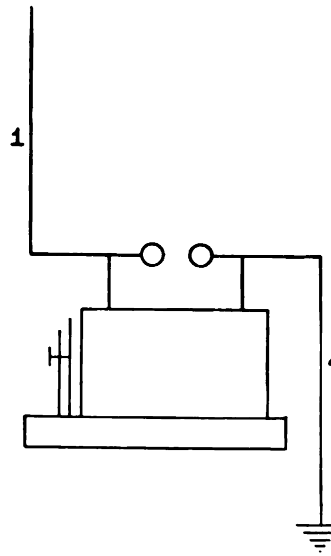


Fig. 6. Marconi's Transmitter.

in 1890, that metal filings enclosed in a tube, termed by him a *radio-conductor*, were marvelously sensitive to enfeebled electric waves impinging upon them. In 1895, Popoff, of Russia, combined with a *coherer* 1, as Branly's detector had been re-named, an electric bell, the hammer 7 of which also served as a tapper to de-cohere the filings, a sensitive relay 6 and a local battery 5, as illustrated in Fig. 5; one terminal of the coherer was connected to a rod 2 elevated in the air while the opposite terminal 3 led to the earth. This formed a self-acting receiver, but was used by him in the study of atmospheric electricity. The spark-gap is shown at 4.

This was the state of the art when Marconi, of Italy, in 1895 began his experiments with a view to long-distance transmission. In his earlier trials in Italy, the young man employed the induction coil and oscillator in transmitting, just as Hertz did before him, but later he ascertained that if one side of the oscillator was connected to a wire 1 suspended in the air, and the opposite side was connected to the earth 2, as in Fig. 6, the energy would be radiated in the form of electric waves to much greater distances than was possible with the simple oscillator designed by Hertz. The receiver used by Marconi in connection with his transmitter was very like that of Popoff except that he added a Morse register and adjusted the mechanism to imprint the received impulses in dots and dashes in accordance with the signals transmitted.

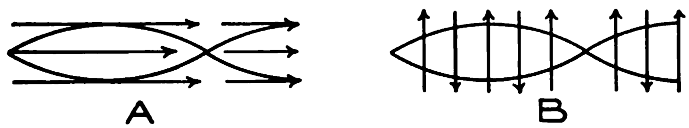
The results attained by Marconi bring the history of wireless telegraphy to the time of its commercial adoption in 1897. Since then there has been a multitude of workers, all of whom have bent their efforts to eliminating its defects, and these men and their work will find a place in the succeeding pages of this text.

PRINCIPLES.

Ether. The first principles upon which the theoretical structure of wireless telegraphy is based are identical to those evolved by Faraday and Maxwell to account for all the phenomena of light, since in either case the waves are electromagnetic in character and are transverse vibrations in and of the ether.

In accepting the hypothesis of an all-pervading substance, termed the electromagnetic medium, it is neither necessary to know its essential form nor its composition, for just as sound may be sent through the air without a knowledge of its constituent parts, so also may electric waves be propagated likewise through the ether. But if the laws of either sound or electric waves are to be deduced then some of the characteristics of the medium in which they are set up and through which they travel must be known, and in working out the system of sequences that governs the action of light, mathematicians come to conclude that ether is a highly attenuated substance, that it possesses elasticity and rigidity, that it has density and that it is incompressible. Thus it will be observed that ether is closely related to electricity yet it partakes of some of the properties of gross matter, and while Sir Oliver Lodge has pointed out that electricity may be a product of shearing the ether, J J. Thomson has done much to indicate that corpuscular matter is of etheric origin.

The constants of the ether have been determined empirically and its specific inductive capacity is taken at 1 which is expressed symbolically by the letter K, while its density is assumed to be about 936 one-sextillionths that of water and is represented by the Greek letter μ. Now μ divided by K equals the velocity of light and all other forms of electromagnetic energy or $\frac{\mu}{K} = 186{,}500$ miles per second.



Air Waves and Electric Waves.

Fig. 7.

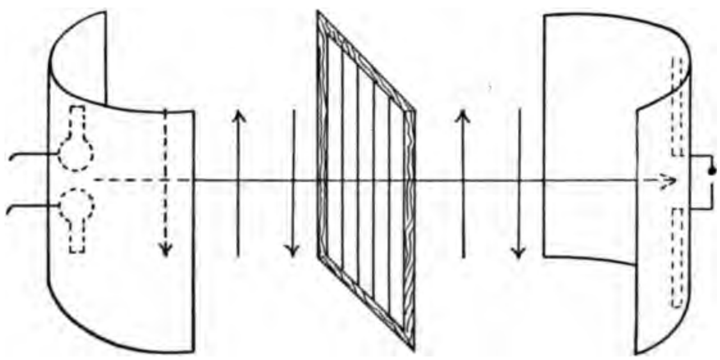
Electric Waves. Undulatory, or wave, motion through the air and that taking place in the ether are different in that the first consists of longitudinal thrusts due to one molecule of matter striking another, while in the latter the motion is caused by transverse vibrations taking place across the line of propagation due to polarized stresses in the ether as shown in Fig. 7, A and B respectively. *Electromagnetic*, or to use the common abbreviated term, *electric waves*, are, however, like sound waves in a number of limiting cases, as for instance, they may vary greatly in length and yet the speed at which they travel in their respective mediums remains constant; again, just as in air, waves of different lengths produce different tones when they impinge on the ear. waves in ether, of very short but varying lengths, reflect dissimilar colors, the violet being the shortest and the red the longest visible waves.

An electric wave a little longer than the red is invisible to the eye, but its effects may be felt in the form of radiant heat. Between the short, radiant heat waves and the long electric waves produced by the disruptive discharge of an electric spark there is a wide gap, yet they are identical except when their lengths are considered.

Because they are invisible and the senses of man incapable of perceiving them except by the aid of some exterior physical means, the existence of electric waves had not been proven by experiment until 1888, when Hertz demonstrated their characteristics, showed a method for producing them, and a simple means by which they could be detected and their effects observed.

Electric waves of whatever length are the result of charges of electricity in rapid motion; if the charge of an atom is set into vibration it will emit a very short wave length, say 271 ten-millionths of an inch which is that of red light, but if a pint Leyden jar is discharged its oscillations will send out waves 50 or 60 feet in length.

Electric Oscillations. Since all waves in ether are due to transverse vibrations they should follow the same physical laws,

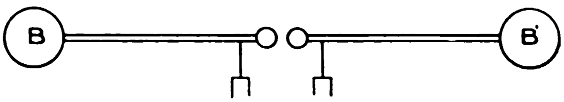


Polarized Electric Waves.

Fig. 8.

and to prove that the long electric waves were identical with those of light, Hertz reproduced all the known optical experiments; showing that waves from his oscillator traveled in straight lines, by reflecting them from the surfaces of metals; that they could be refracted, by passing them through huge prisms of pitch; he formed shadows by intercepting them with his own body and other objects; and finally he polarized them by means of a grid made of a number of parallel wires as shown in Fig. 8.

Disruptive Discharge. To set into vibration the electric charge of an atom for the purpose of producing light, it is usual to employ heat, but to obtain long electric waves for experimental purposes or for wireless telegraphy there is only one method known to science and that is by discharging a charged Leyden jar or other oscillator formed of opposite metal conductors B, B′ and separated by a spark-gap as shown in Fig. 9; this form of oscillator is



Open Circuit Oscillator.

Fig. 9.

charged by an induction coil or other high-tension apparatus. When the spark takes place, the opposite sides or arms of the oscillator discharge into each other, thus equalizing their difference of potential through the spark or disruptive discharge.

The moment the spark occurs, the static charge of the oscillator is changed into kinetic energy which surges through the system to and fro, like a straight steel spring suddenly released; but while the energy of a spring is damped out in the making of air waves, the electric oscillations are transformed into electric waves in the ether, but in both cases the energy decreases in geometric progression from maxima to zero as described in the curve, Fig. 10.

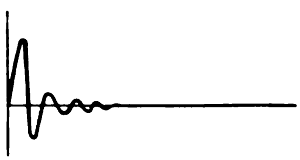


Fig. 10. Electric Oscillations.

For this reason the waves can be emitted only periodically, and before another train of waves can be started, the oscillator must be recharged, and this requires time. The charging is done automatically by having the terminals of an induction coil connected with the arms of the oscillator so that as soon as the oscillatory currents set up by the spark have damped out their energy in electric waves, the high-tension current generated by the coil will instantly recharge the oscillator to its maximum capacity, when it will again break down the thin film of air and the cycle of operations will be repeated.

To determine the length of an electric wave, it is necessary to know not only its velocity, which has been previously calculated, but also the period of oscillation of the system radiating the waves; the latter depends upon the constants of the oscillator circuit, that is, its capacity C, its inductance L, and its resistance R. These factors are in turn governed by its length and other dimensions, and the time of oscillation T may be found by the formula $T = 2 R \sqrt{LC}$; the resistance may be considered negligible in a simple open circuit where oscillations are of sufficient frequency to send out electric waves. The length of the wave is easily found by dividing the velocity v by the number of waves n, or $\frac{v}{n} =$ the wave length.

Electric waves emitted by a simple oscillator of the Hertz type give rise to free spherical waves in space, and the writer has ever advocated the theory that this is the form of waves radiated by the ærial wire and earthed-oscillator system of a wireless telegraph transmitter, while Blondel, Taylor, and Fessenden have promulgated a theory in which the waves are assumed to be hemispherical or half-waves which slide over the surface of the earth or sea; the illustrations, Fig. 11, A and B respectively, show graphically these two view-points.

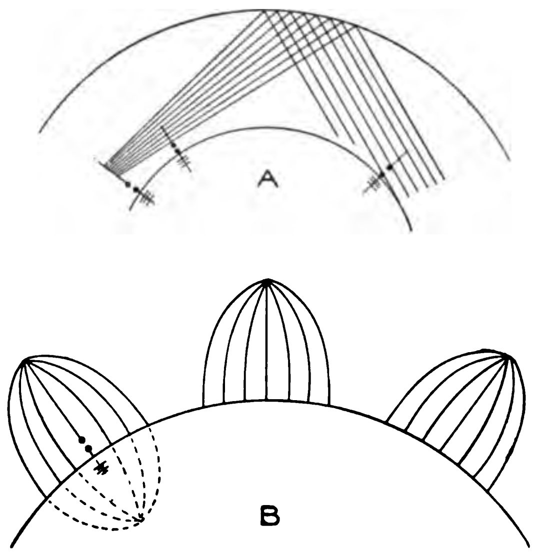
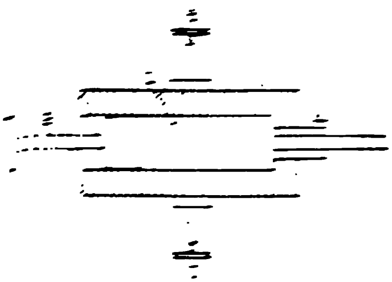
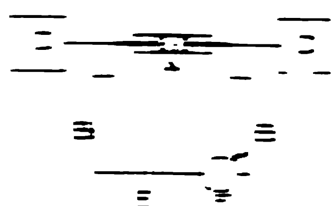


Fig. 11. Electric Wave Propagation.

Having ascertained the process by which low-voltage direct currents are transformed into currents of high frequency and potential, and how these oscillations radiate their energy into space in the form of electric waves, the final fundamental principles involve their reception and indication. While all insulating





single cell E, and a galvanometer, or a telephone receiver F, as in Fig 13; D and D represent the capacity plates and B, B the internal circuit. It is obvious that when the filings cohere, the current from the cell will readily flow through the circuit including the galvanometer, its needle will then be deflected and it will so continue until the filings are restored to their normally high resistance, which condition may be easily attained by merely tapping the tube with a pencil; in practice, the decohesion of the particles is usually effected automatically by an electro-mechanical device.

In commercial wireless telegraphy, the ærial wire at the sending station is connected with the earth through the medium of a spark-gap, as A in Fig. 14, which constitutes the circuit wherein the current oscillates. At the receiving station, the coherer is connected to the lower terminal of the vertical wire and to the free end of the wire leading to the earth, as indicated at B, forming the resonator.

Marconi ascertained that the energy of the waves did not diminish in intensity when the distance was increased if the length

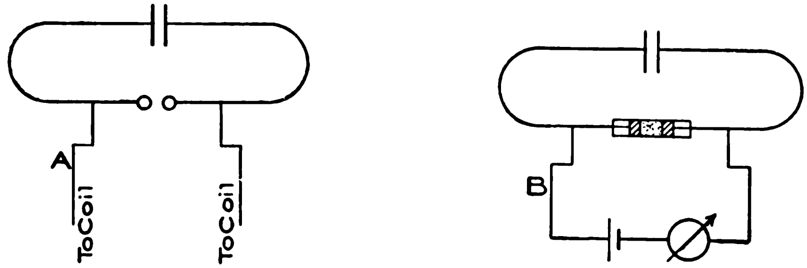


Fig. 15.

of the ærial wires were increased as the square of the distance, that is, by doubling the height of the wires the waves would be transmitted to four times the distance, the initial energy remaining the same. These are the first principles of the action of electric waves and the operation of the earliest and most simple forms of wireless telegraph systems, while those of a later and more complex nature depend on electrical resonance and electro-mechanics.

It has been previously shown that the length of an electric wave depended upon the coefficients of the oscillator, and it has also been pointed out that a resonator in the field of force would have oscillations produced in it by the impinging waves.

Resonance. Now it is well known that when an oscillator and a resonator have exactly the same electrical dimensions, that is, inductance, capacity, and resistance, the currents set up in the resonator will be much stronger than where the circuits are not in resonance with each other. By applying the laws of resonance to wireless telegraphy, inventors have striven to produce the same conditions on a commercial scale that have been obtained in the laboratory in order to provide a method capable of signaling selectively.

The oscillators and resonators previously described were of the *open-circuit* type, having two oppositely disposed arms; but for resonance effects *closed-circuit* oscillators and resonators, illustrated diagrammatically in Fig. 15, at A and B respectively, give the maximum results. Conversely, open-circuit oscillators are the best radiators of electric waves, damping out the energy in two or three swings while the closed-circuit type permits the current to oscillate for a long period of time and consequently very feeble electric waves are emitted. Hence wireless telegraphy systems with open circuits give the best results over long distances, but as these are co-resonant, in virtue of the capacity of the earth with which they are connected, every receiver is in syntony with every transmitter, and therefore they have no individual selective properties. The efforts to combine open and closed circuits to obtain the advantages of long-distance transmission and selective signaling has led to many ingenious relations and the production of several syntonic systems.

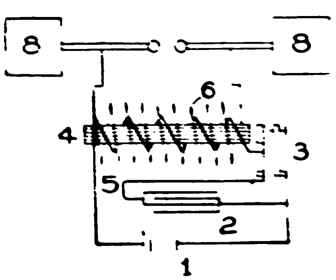


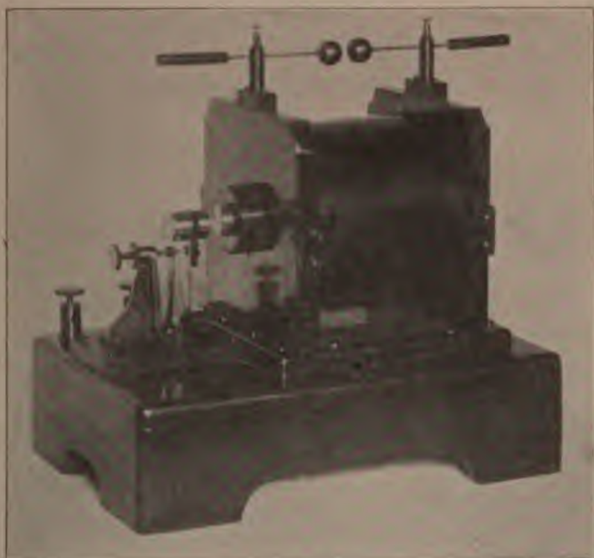
Fig. [illegible]

APPARATUS.

The apparatus comprising the transmitter consists of a source of electromotive force, a battery or dynamo, a key, an induction coil or transformer, and an oscillator. The appliances forming a receiver of the simplest type include a wave detector, a cell, a telephone receiver, and a resonator; in the earlier and more complex systems, a relay, a tapper, and a Morse register were added.

Induction Coil. There are two methods of transforming low-potential into high-potential currents. The first is by means of an *induction coil* and the second is by using a *transformer*. The term induction coil differentiates this apparatus from that known as a transformer; the former being supplied with an interrupter and a condenser and energized by a low-voltage direct current, while the latter has neither of the devices just cited and is operated by a low-voltage alternating current.

The induction coil, Fig. 16, is made up of an iron core 4, formed of a number of soft iron wires having wound around them



Induction Coil.

Fig. 17.

two layers of heavy wire 5, called the *primary coil* or *inductor*. One end of the primary leads direct to the battery 1, the other connecting with an interrupter 3, a simple mechanism for automatically making and breaking the current, which is in turn connected to the opposite pole of the generator. Around the "make and break" a condenser 2 is connected in shunt, assuming the contacts of the interrupter to be closed, but when open the condenser is in series with the primary coil.

Outside the primary coil and well insulated from it is the *secondary* coil 6, built up of several thousand feet of very fine wire and thoroughly insulated with a compound of resin and beeswax. The terminals of the secondary connect to the opposite arms 8, 8 of the oscillator. In operation, when the primary coil is energized by the current, the core becomes magnetized and magnetic flux surrounds the coil in a direction paralleling its axis. This causes a current to be induced in one direction in the secondary. When the interrupter breaks the circuit, a current is induced in the opposite direction; this is repeated automatically several hundred times per minute resulting in a high-tension alternating-current flow at the terminals of the secondary coil and which is utilized for charging the oscillator. Fig. 17 is a photographic illustration of an induction coil.

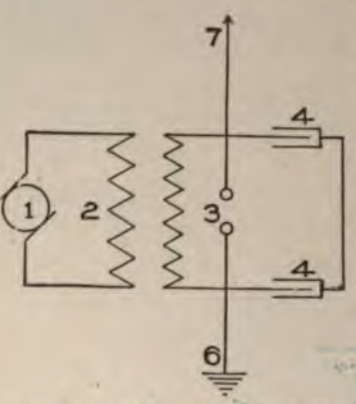


Fig. 18. Transformer Transmitter.

Transformer. In a later method, shown in Fig. 18, the primary winding 2 of an ordinary commercial oil transformer is connected


Marconi Coherer.

Fig. 20.

to the terminals of an alternating-current generator 1, of say, 60 cycles and 500 volts. The ends of the secondary of the coil 3 are joined to a battery of Leyden jars 4, 4. When in action, the

FESSENDEN WIRELESS TELEGRAPH STATION.

National Electric Signaling Company.

reversals of the current in the primary of the transformer induce alternating currents in the secondary coil having the same period but enormously increased potential, the transformer giving about

Fig. 19. Wireless Telegraph Key.

25,000 volts at the secondary terminals. This low-frequency, high-potential current charges the Leyden jars to the limit of their capacity, when they discharge through the spark-gap of the oscillator. 6 is the earthed terminal and 7 the ærial wire.

Keys. In order to break up the current arbitrarily into dots and dashes, a telegraph key is interposed in the primary circuit; the keys usually employed are constructed like an ordinary telegraph key, but are very much larger, like the one in Fig. 19, as the currents to be broken are often in excess of 746 watts or one electrical horse-power. Another form of key, designed to be operated with the rapidity of the ordinary Morse key, is constructed so that the heavy current is broken under oil.

The spark-gap, dividing the ærial wire and the earthed terminal is usually formed of two spheres or discs so that the length of the disruptive discharge may be regulated at will.

Wave Detectors. Of the receiving devices the wave detectors are the most important. These comprise two general classes; those of the first class are *voltage-operated* and are of the coherer type, in which the resistance is lowered by the potential of the oscillations, and the anti-coherer type in which the resistance is increased by the oscillations. Those of the second class are *current-operated* detectors where the current strength of the oscillations varies the resistance of a fine wire or liquid through heat losses by radiation.

A coherer of the filings type is shown in Fig. 20; two silver conductor plugs with platinum wire terminals are forced into a piece of glass tubing leaving a space or pocket for the

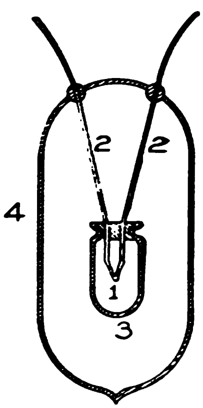


Fig 21. Fessenden Barretter

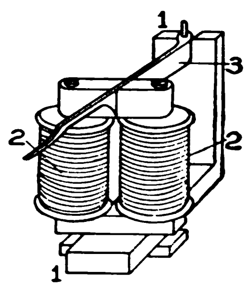


Fig. 22. Polarized Relay.

filings made with a coarse file from nickel and silver in the proportions of 90 per cent of the former and 10 per cent of the latter; the tube is then adjusted, the air is exhausted with a mercury pump, and the tip sealed off. *Anti-coherers* are made by substituting oxide of lead for the ordinary filings between the conductor plugs; the current from the local cell causes minute threads of metal to be built up between the plugs by electrolysis, and these are disrupted by the electric oscillations. *Auto-coherers* are those that need no tapping to bring them back to their normal resistance after the effects of cohesion, but are restored automatically in virtue of their inherent properties.

A barretter or current-operated wave detector is illustrated in Fig. 21; it is made of a little loop of silver wire having a diameter of .002 inch with a core of platinum wire 1 drawn down to .00006 inch in diameter; the tip of the silver loop is then dissolved away exposing the platinum filament; this done, the ends of the loop are attached to the leading-in wires 2, 2 sealed in a glass bulb which is finally enclosed in a silver case. The silver shell is shown at 3 and the glass globe at 4. A new form of barretter employs a very small column of nitric acid and a minute platinum wire immersed in the liquid so that the resistance of the latter is concentrated closely to the point. Anti- and auto-coherers and barretters can be used only in connection with a telephone receiver,

Marconi Polarized Relay.
Fig. 23.

for their resistance variations are too limited to permit the relay to be actuated; the filings coherer is the only type of detector known that can be employed in combination with a relay.

Relays. Of relays there are several forms, but the *polarized relay*, shown in Fig. 22, is the only one sensitive enough to be used in conjunction with a coherer for long-distance work. A polarized relay is provided with a permanently magnetized armature 3 instead of the soft iron one of the ordinary instrument; it has two magnets, one an electromagnet 2, 2 and the other a permanent magnet 1, 1; by this arrangement, when no current is passing through the coils of the electromagnet, the poles will be north; but when the current flows, one of the poles is more strongly magnetized while the other changes its polarity to south. There are several modifications of the polarized relay, but their principles of operation are the same. Fig. 23 shows the type used in wireless-telegraph receivers.

De-Coherer. Next in importance is the tapper, or de-coherer, for restoring the filings after the oscillating current has cohered them. The construction of a tapper is much like that of the ordinary electric bell with an automatic contact breaker; but different from the latter in that the hammer of the tapper has a very low time constant so that its vibrations can be very rapid. Such a tapper is shown in Fig. 24, and is, it will be observed, provided with a device for supporting and adjusting the coherer so that the strength of the stroke of the hammer may be varied at will.

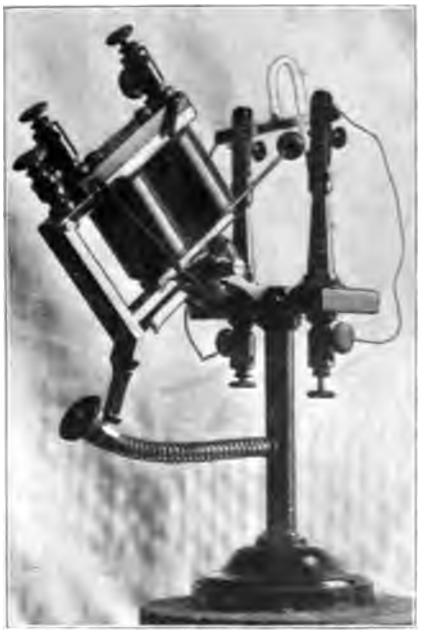
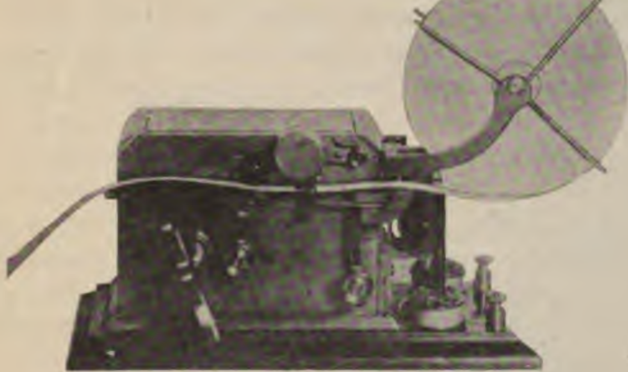


Fig. 24. Guarini Tapper.

There are several instruments for translating the received impulses into readable Morse, as for instance, the galvanometer, the telephone receiver, the ordinary sounder and the Morse register. The three former appliances are so well known that they need not be described here. The register is employed where it is desirable to have a permanent record of the received message, and a general idea may be gained of its construction and operation by referring to Fig. 25.

Register. The register is an electro-mechanical apparatus comprising a spring motor, the purpose of which is to draw a tape of paper under an inked disc operated by an electromagnet.



Morse Register.
Fig. 25.

When a current is passing through the coils of the electromagnet, the inked disc, which is attached to the armature, is drawn into contact with the paper and held there until the current ceases; in this way the dot and dash code is formed and imprinted on the tape.

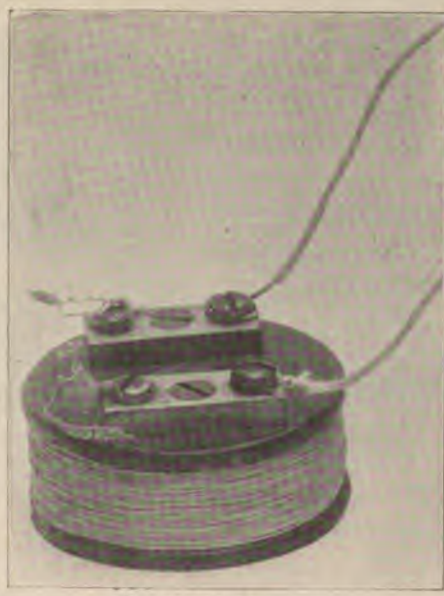
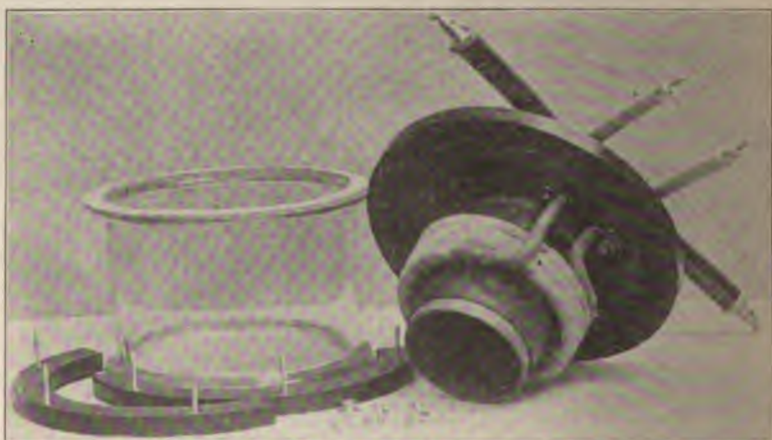


Fig. 26. Choking Coil.

The above appliances are the principal ones making up the ordinary wireless telegraph systems, but there are a number of other and minor devices utilized to render more accurate the working of the instruments. One of these is the *choking coil*, made of a long, fine insulated wire doubled back on itself and then wound on a wooden spool as shown in Fig. 26; these coils are interposed in the local circuits of the receiver to cut off high-frequency currents which may be set up by sparking, either in the coherer or between the relay contacts.

Oscillation Transformers are used in many systems of recent design; these are constructed for stepping up or down high-frequency and high-potential electric oscillations, and are employed in both the sending and the receiving circuits. The transmitting transformers have an inductor or primary of three or four turns of heavy wire wound *outside* the secondary coil which is formed of thirty or forty turns of fine wire, when the coils are then immersed in oil; two views of a typical transformer are illustrated in



Braun High Potential Transformer.

Fig 27.

Fig. 27. Smaller transformers are often employed in the receiving circuits, and consist of simply a primary and a secondary coil insulated in the usual manner.

Inductance coils and *condensers* are also largely used in wireless telegraph practice for the purpose of increasing the inductance and capacity of the oscillators and therefore the waves emitted by them. They are also useful for tuning a closed-circuit to an open-circuit as well as to obtain resonance between the transmitter and receiver. Inductance coils are formed of a large number of turns of heavy wire with sliding contacts so that any desired value of inductance may be procured. Condensers for providing suitable capacities can be made up of Leyden jars or metal sheets immersed in oil where high tensions are employed, but in receiving circuits, those of the ordinary mica type are used. Finally where detectors of the coherer type are utilized a metal case is provided which encloses not only the coherer but the relay, tapper, and local cells leaving the register alone exposed. The object of the screening box is to protect the delicate and sensitive instruments from the powerful oscillations of the transmitter in the immediate vicinity.

With an understanding of the subsidiary apparatus comprising the component parts of transmitters and receivers and the principles involved, it is now easy to follow the intricacies of the various systems that complete the art of wireless telegraphy.

SYSTEMS.

The many different systems for sending messages through space without wires may be classified under two general heads, namely, those designed without regard to selectivity, and those where electrical resonance has been brought to bear in order to prevent interference. Those of the first class are termed *non-syntonic* and those of the second class *syntonic* systems.

Marconi. *First form.* The first complete system of wireless telegraphy was conceived and patented by William Marconi, who, by employing greater power, larger radiating surfaces and improving its details, was enabled to increase its effective range from 300 feet to 2,000 miles. His first apparatus was simply an open-circuit apparatus of the non-syntonic type as a reference to the diagram Fig. 28, will show.

The transmitter A includes an induction coil 1, energized by a battery 2, the current being broken up into the Morse code by the key 3; the coil is equipped with a spring interrupter 4; the terminals of the secondary are connected to either side of the spark-gap 5, which with the ærial wire 6 and the earthed terminal 7, forms the oscillator system. The receiver B is made up of a coherer 1, the polarized relay 2, and the cell 3, all of which are connected in series and comprise the first *internal circuit.* The second internal circuit includes the contact points of the relay 2, the Morse register 4, the battery 5, and the tapper 6; the tapper

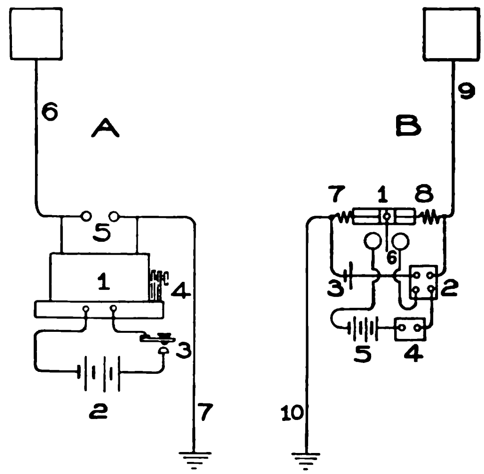


Diagram of Original Marconi Transmitter and Receiver.

Fig. 28.

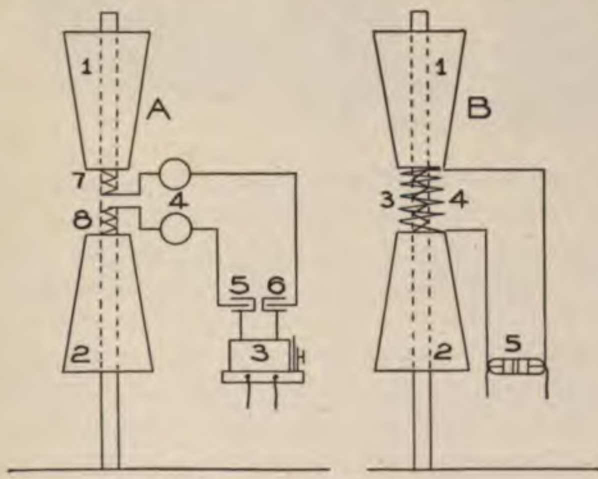
and register may be in series or parallel; the ærial wire 9 and the earthed terminal 10 form the resonator. Choking coils 7 and 8 are placed in the first internal circuit between the coherer and the relay to prevent oscillations from the resonator from wasting their energy in the relay coils, as well as to prevent those originating at the contacts of the relay from acting on the coherer. To the free ends of the ærial wires were attached large sheets of metal termed capacity areas, but these are no longer deemed necessary. A photograph of a Marconi station at Babylon, Long Island, is given in Fig. 29.

Lodge. To Sir Oliver Lodge is due the credit of having evolved the first syntonic electric-wave apparatus based on the laws of resonance, and since nearly all the succeeding systems utilize these principles a brief review of his arrangement may prove use-

Marconi Wireless Telegraph System.

Fig. 29.

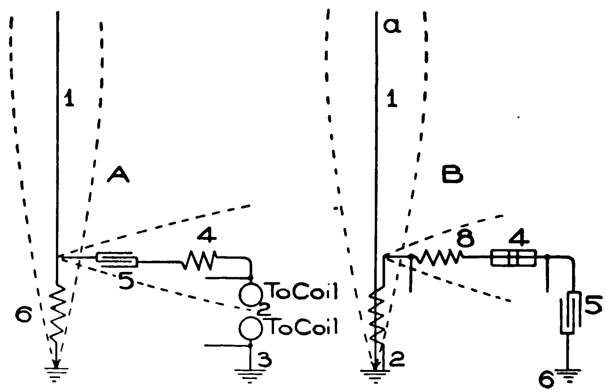
ful. In this system, instead of the usual ærial and earth wires, two conical metal capacity areas are substituted; in Fig. 30, A, 1, and 2 represent the areas which are charged by an induction coil



Lodge Syntonic System.

Fig. 30.

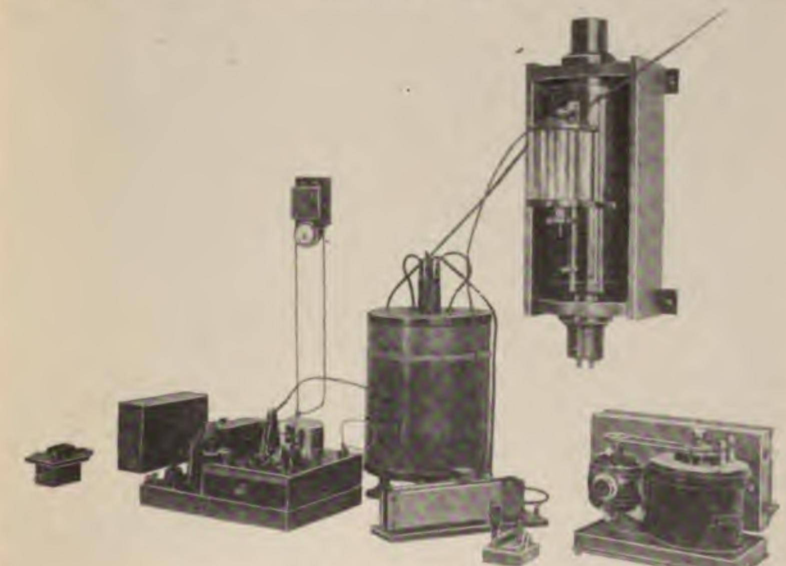
3 and which discharge through the spark-gap 4; the value of capacity can be changed by means of the adjustable condensers 5 and 6; the values of inductance are also made variable by the coils 7 and 8; the resistance of the circuit is negligible; it is obvious that a wave of predetermined length may now be obtained since it depends on the period of oscillation and this on the inductance and capacity of the circuit. The capacity areas are insulated from the post which supports them. The receiver B is formed of two similar capacity areas 1 and 2, and these are connected through the primary of an oscillation transformer 3, the secondary of which 4 leads to the coherer 5; the relay, tapper, and register are not shown but operate as previously described.



Diagrammatic View of Slaby-Arco Multiple-Tuned Wireless-Telegraph Transmitter and Receiver.

Fig. 31.

The Slaby-Arco System, of German manufacture, is now extensively used in the United States Navy, and though retaining the aerial wires and earthed terminals it is based on certain resonance phenomena as will be seen. When an oscillation is set up in a wire, it will emit a wave four times its own length; if the wire is connected directly to the earth, as shown in Fig. 31, the greatest amplitude will be at the free end of the wire while the nodal point will be at the earthed end as indicated by the dotted lines. If, in the transmitter A, the earthed radiating wire 1 is connected to the spark-gap 2 and to the earth 3 through the inductance coil 4 and the condenser 5, then a combination of an open and a closed circuit is formed, since the earth serves to close the circuit containing the spark-gap. Assuming that the inductance 4 and the capacity 5 is equal to that of the wire 6, then oscillations set up in the former will be impressed upon the latter which will radiate the energy in electric waves. In the receiver B similar conditions prevail; 1 is the receiving ærial wire or *antenna*, the oscillation having its greatest loop at *a*, 2 is the nodal point forming an open-circuit resonator; a closed resonator circuit is formed by the inductance 8, the coherer 4, condenser 5, and the earth 6; the point of greatest amplitude of the oscillations is arranged to correspond with the



Slaby-Arco System.

Fig. 32.

coherer which receives the maximum potential as indicated in the dotted lines. A photograph of the complete system is shown in Fig. 32.

Marconi. *Second form.* In seeking a solution for the problem of selectivity, Marconi produced a second system in which he eliminated the ærial wire, as in Lodge's scheme, but since grounded terminals were essential to long-distance transmissions, he retained these features. Fig. 33 is a diagrammatic view of the arrangement; the oscillator and resonator are compound, that is, each is of the nature of an open and a closed circuit. The transmitter A shows two concentric cylinders 1 and 2, separated by an air space and forming in reality a huge Leyden jar. The inner cylinder leads to earth and is also connected to the outer cylinder through the spark-gap 4 and the inductance coil 5. The receiver B has a similar cylinder 1 and 2; the outer is connected to the inner through the primary of a small oscillation-transformer 4 and inductance 5; the coherer 6 is connected to the secondary coil thus forming another closed circuit. These cylinders do not radiate their energy in two or three swings, yet the oscillations are not sustained to such a point as to enfeeble the emitted waves; when syntonized to each other, selectivity may be obtained within certain limits.

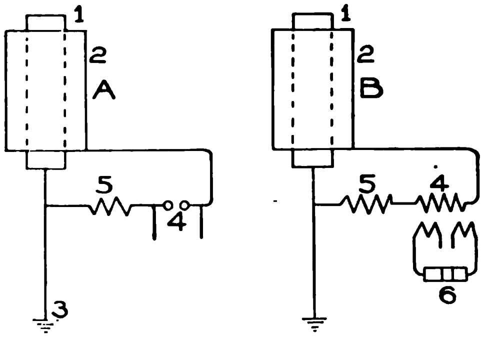


Fig. 33. Diagram of Marconi Selective Wireless-Telegraph System.

Braun-Siemens and Halske. One of the best theoretical syntonic systems is the Braun-Siemens and Halske of Germany. Oppositely disposed to the one just described, Dr. Braun has retained the ærial wires, but discarded the earthed terminals. The arrangement is shown graphically in Fig. 34. The fact that the ærial wire is one-fourth the length of the emitted wave, that the oscillations in one circuit can be transformed into another circuit, and that a closed circuit is a persistent oscillator while an open circuit is a strong radiator led to the design of the following apparatus:

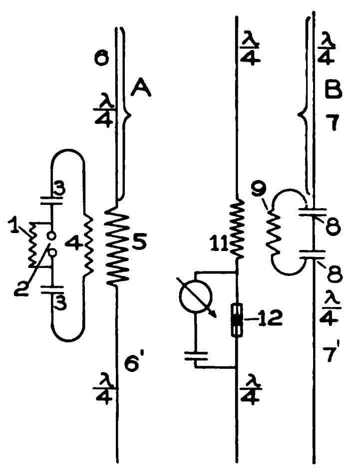
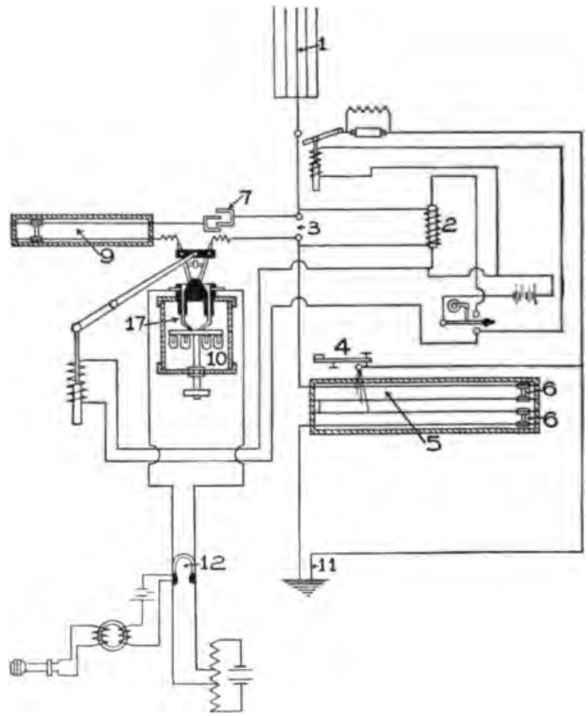


Fig. 34. Schematic Arrangement of Braun's Wireless-Telegraph System.

Braun Resonance System.
Fig. 35.

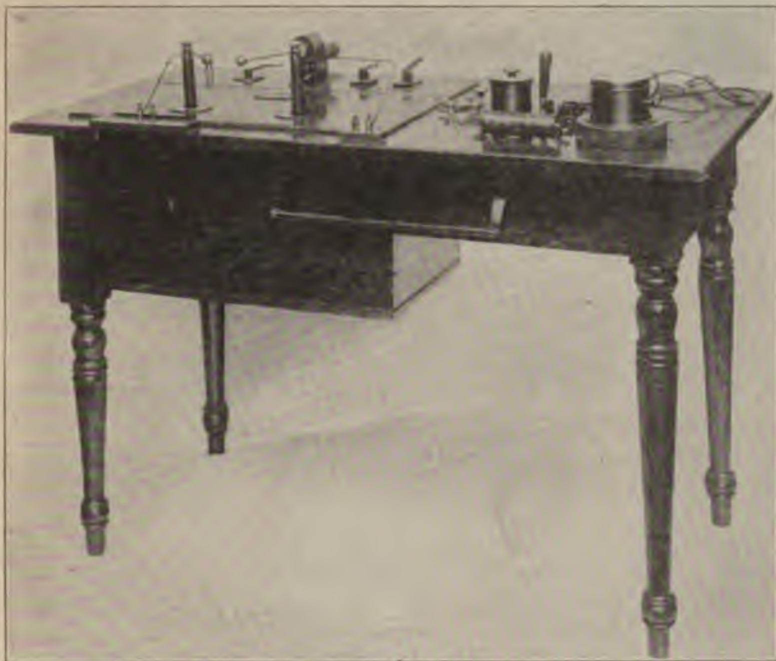
In the transmitter A, the secondary of an induction coil 1, charges the oscillator system of which the spark-gap 2, the condensers 3 3, and the primary 4 of a high-tension transformer are the complement; the transformer is shown in Fig. 27. The secondary 5 of the transformer connects with the ærial radiating wire 6, while the lower wire 6′ is made equal in length or it may be an inductance coil and capacity equal to that of the ærial wire. The receiver B has a similar ærial wire one fourth $\left(\frac{\lambda}{4}\right)$ the length of the received wave length connected with a closed resonator circuit formed of the condensers 8, 8 and the primary of a small oscillation transformer 9; the antenna 7 is balanced by an equal amount of capacity and inductance at its lower end 7′; the coherer 12 is placed in one arm of an open-circuit resonator; the secondary 11, of the transformer connecting with an opposite arm of equal electrical dimensions, completes the apparatus. Fig. 35 is a photographic reproduction of the Braun-Siemens and Halske system.



Fessenden Combined Sending and Receiving Apparatus.

Fig. 36.

Fessenden. An American system designed by Reginald A. Fessenden is shown in Fig. 36; it contains several novel features, as the use of a current-operated wave detector, invented by Prof. Fessenden and termed by him a barretter. The tuning of the circuits is accomplished by a grid formed of wires immersed in oil that gives a variable capacity and inductance without the use of



Fessenden Tuned System.

Fig. 37.

coils or condensers. By means of sliding contacts on the wires, the open-circuit oscillator may be tuned to the closed-circuit system so that both have exactly the same period.

By referring to the diagram the arrangement will become clear. In this drawing the transmitter and receiver are combined as they are in practice, since the same ærial and earth wires serve for sending and indicating the waves. The ærial wire **1** is supplied with energy from the induction coil 2 through the spark-gap 3; one side of the gap leads to the key 4, making connection with the tuning grid wires 5; these can be adjusted by the sliding contacts 6, 6 finally leading to the earth at **11**. The receiving devices comprise a condenser 7 and a tuning grid 9 which connects with the barretter 10 through a holder containing a number of them at 17, an electromagnet automatically breaking the circuit in which they are placed by the operation of the induction coil; the resonator circuit is completed by antenna **1** and the earth **11**; the variation

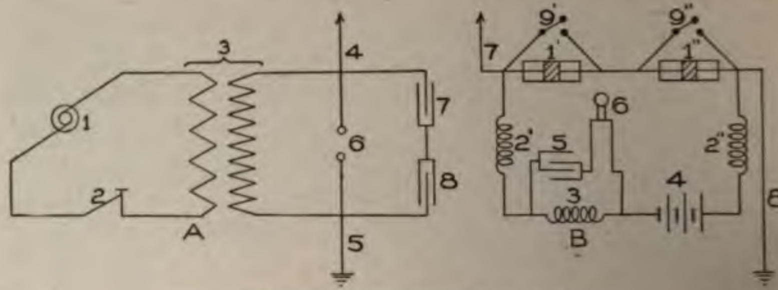


Diagram of DeForest Wireless-Telegraph System.

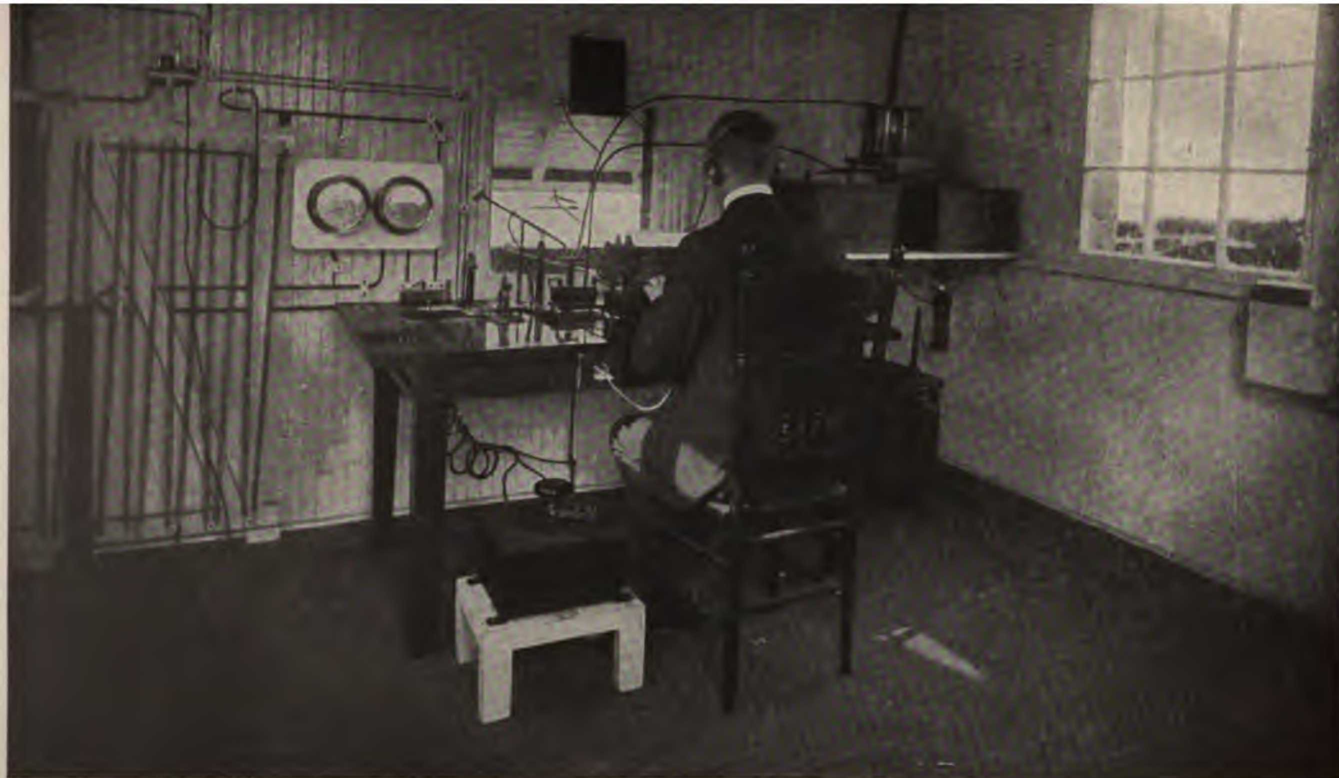
Fig. 38.

of the current is read by means of a telephone receiver 12. The apparatus is very compact as Fig. 37 shows, it is rapid in operation and accurate in its translations.

American De Forest. Another system using the telephone receiver as a means of indication is the American De Forest. This was the first commercial system to employ an alternating-current generator and an oil transformer to charge the oscillator system.

DeForest System Transmitter.

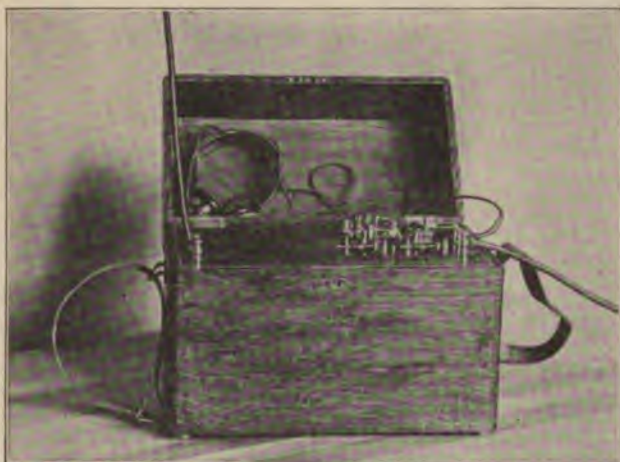
Fig. 39.



INTERIOR STANDARD FESSENDEN 250-MILE LAND STATION.

National Electric Signaling Company.

The transmitter A, Fig. 38, includes an alternating-current generator 1, an ordinary Morse key 2, with contacts breaking under oil, and a transformer 3. The ærial wire 4 and earthed wire 5 form a simple open-circuit oscillator through the spark-gap 6; this system is supplied with energy by the condensers 7 and 8 which are charged by the secondary of the transformer. The receiver in its simplest form comprises a self-restoring detector invented by Dr. De Forest and E. H. Smythe, called an *electrolytic responder*—previously described under "Principles"—a cell and a telephone receiver. In practice, it takes on the form shown at B; two responders 1′, 1″ are connected with the ærial wire and earth; the



DeForest Receiver.

Fig. 40.

internal circuit includes the responders 1′, 1″, the choke coils 2′, 2″, a resistance of 5,000 ohms 3, battery 4, condenser 5, telephone receiver 6, antenna 7, ground 8, and shunt switches 9′, 9″. This system has met with favor at home and abroad due largely to its simplicity and efficiency. Fig. 39 illustrates the transmitter and Fig. 40 the receiver.

Branly-Popp. Especial interest is attached to the Branly-Popp system in virtue of the fact that Prof. Branly is the original inventor of the coherer. The chief feature of the newly-designed apparatus is a tripod coherer and the elimination of the regulation tapping device. Fig. 41 is a diagram of the connections and Fig. 42 shows the apparatus. The transmitter is of the usual induction-coil, open-circuit oscillator type. The coherer consists of three highly polished tapering steel legs, the lower points of which are

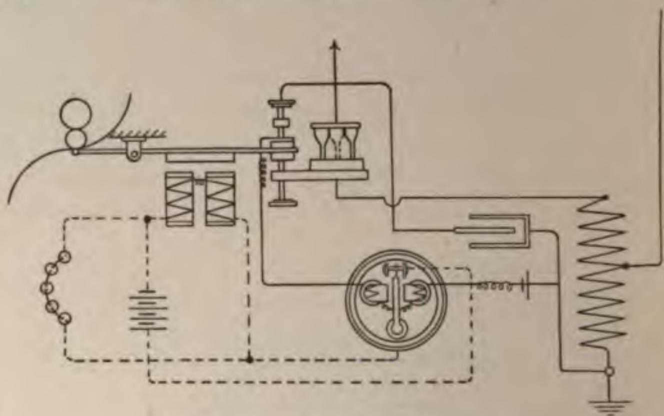
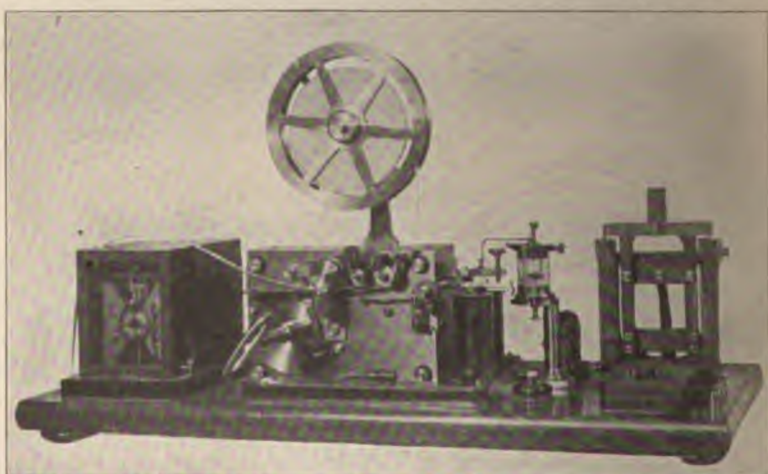


Diagram Branly-Popp System.

Fig. 41.

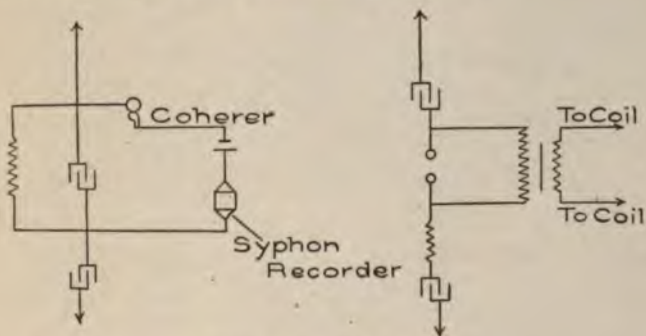
slightly oxidized. The legs are fastened to a metal disc at the top, the points resting on a polished steel plate. In the photograph it will be observed that the coherer is placed immediately back of the



Branly-Popp System.

Fig. 42.

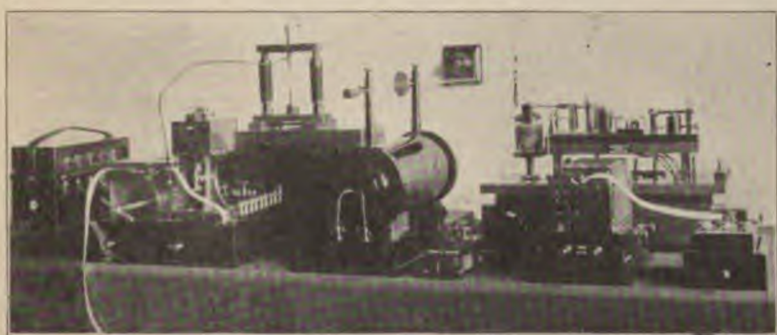
electromagnets of the Morse register, and when the armature is attracted by the magnets, a projecting hammer serves to tap the coherer, restoring the high resistance between the points and making the plate ready for the succeeding impulse.



Lodge-Muirhead System.

Fig. 43.

Lodge-Muirhead. Another recent example of the advances in wireless telegraph practice is the Lodge-Muirhead system, the schematic arrangement being shown in Fig. 43 and the complete apparatus in Fig. 44. The combination of open and closed oscil-



Lodge-Muirhead System.

Fig. 44.

lator and resonator circuits will be recognized as well as the inductance coils and condensers for obtaining resonance effects. The receiver embodies a new rotating mercury coherer, in which a polished steel disc is made to revolve so that its edge runs in, and therefore forms contact with, a column of mercury. Instead of a

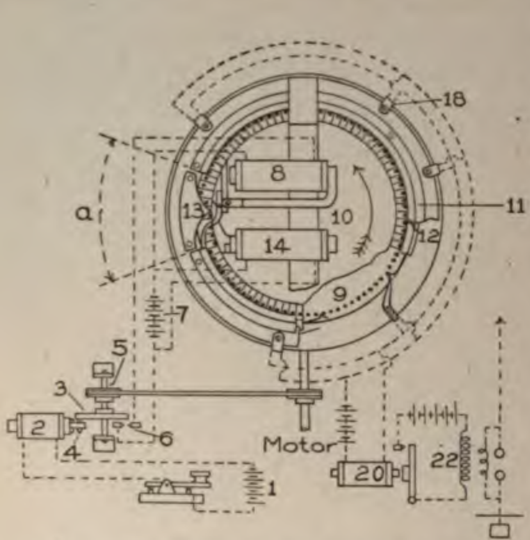
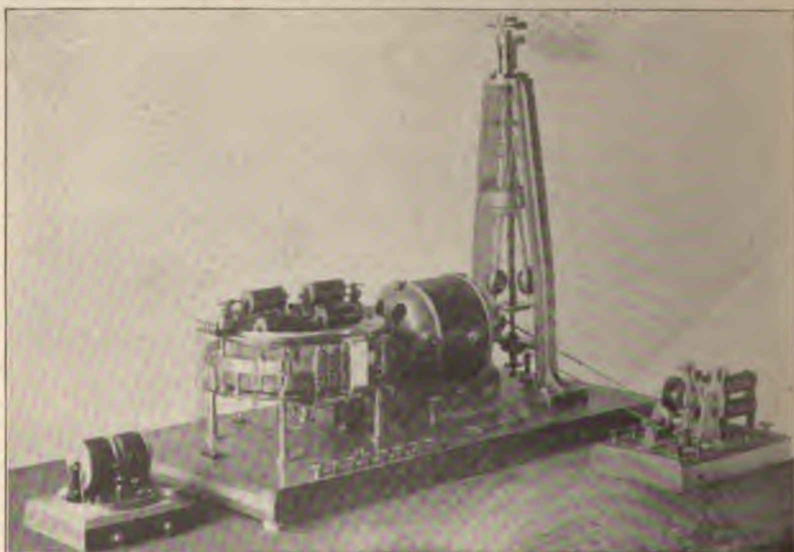


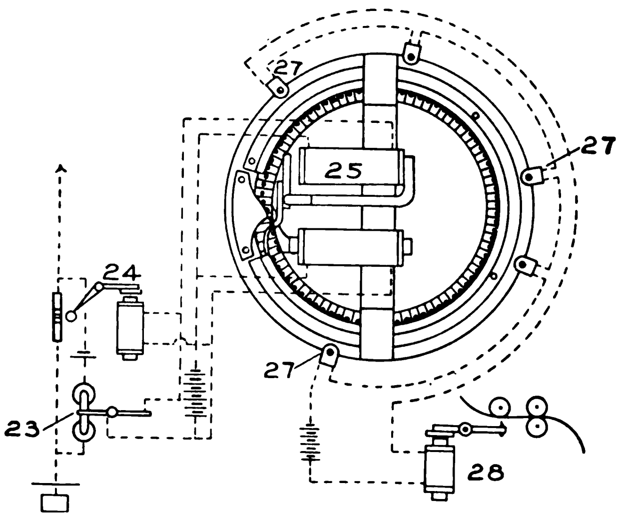
Fig. 45. Transmitter Showing Connections Between Dispeŕser and Induction Coil.

telephone receiver or a Morse register, a syphon recorder such as is used for receiving cable messages is employed and, owing to the comparatively wide variations of resistivity of the coherer, this enables them to be connected direct, thus doing away with the usual relay. The equipment also includes a perforator, for preparing the messages so that they may be sent by an automatic or machine transmitter, although a manually operated key may be used if desired.



Anders Bull's Electro-Mechanical System. Transmitter.
Fig. 46.

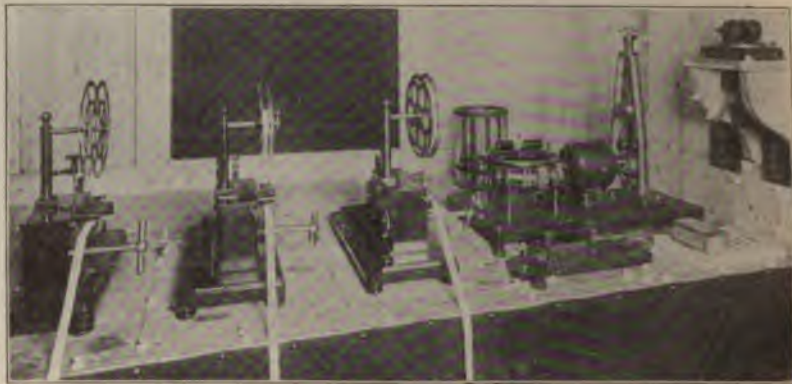
Bull. In all the foregoing systems, where electric signaling was one of the objects to be attained, the desired results were striven for by utilizing the laws of electrical resonance. The solving of the difficult problems of syntonization has, however, been attempted along other and more concrete lines embracing electro-mechanics of which the following inventions of Anders Bull are the best examples. In this system, the transmitter consists of a *disperser* and an induction coil shown in Figs. 45 and 46; when in operation its function is to send out a fixed number of wave im-



Receiver, Showing Connection Between Coherer Relay, Morse Register, and Collector.

Fig. 47.

pulses per given period of time; these waves actuate different receivers adjusted in accordance with the pre-arranged time intervals. When the key closes the circuit of the battery 1 and the electro-magnet 2, the armature of the latter releases a clutch on the disc 3 from the pin 4; the disc is rotated by a frictional shaft 5 making five revolutions per second. Every revolution of the disc causes the pin 6 to close the circuit including the battery 7 and the electromagnet 8; the disperser proper consists of a disc having attached thereto four hundred straight steel springs 9, their free ends passing through a radial slot in the upper revolving disc 10; a brass ring 11 serves as a guide for the spring points and when the disc revolves



Bull's Electro-Mechanical System. Receiver.

Fig. 48.

they slide within a U-shaped groove 12 if attracted by the magnet or within the ring itself when there is no magnetic pull upon them. A bronze arc 13 causes the springs to bend toward the magnet 14, and being energized by the battery, they slide into the groove where they finally close the circuit of the magnet 20 controlling the induction coil 22. As the disc rotates, the springs make contact with projections extending around the frame at certain predetermined intervals and in this way waves of prescribed frequency are consequently emitted.

When these periodically emitted waves impinge upon the antenna of the receiving apparatus, Fig. 47, the coherer closes the circuit of the relay magnets 23; and the tapper 24, and the collector magnet 25 are brought into action. The mechanism of the collector is exactly like that of the disperser and can therefore be instantly converted into a disperser. The discs of the disperser and collector revolve synchronously, hence if five electric wave series are transmitted, five springs will close the circuit at given intervals of time; the spring points 27 of the collector having the same relative arrangement as in the disperser the impulses operate similar contacts controlling the Morse register 28. In this system interference is not obviated, yet any one of a number of receivers in the same field of action may be operated to the exclusion of all others. The Bull receiver is shown in Fig. 48.

THE TELAUTOGRAPH.*

Electrical transmission of handwriting has engaged a certain amount of attention ever since telegraphic transmission of printed characters was successfully carried out.

As early as 1886, Cowper and Robertson brought the writing telegraph[1] into a fairly operative form. This instrument was adapted to operate several receivers in series in "reporting" service, where the regular news ticker service was unobtainable or too expensive. The system was put to some use, chiefly in Pittsburg and vicinity.

The writing was received on a paper tape, advanced at constant speed by clockwork. No pen-lifting device was provided and the words were connected together by a mark of the pen, making figure work poor. As the characters were formed by the combination of the pen motion and the tape motion, a certain amount of practice and skill was required to produce a legible message.

The electrical features were as follows: two independent variable currents were obtained from the transmitter; these passed over lines to the receiver where they traversed two electromagnets set at right angles to each other, and so influenced their effect upon a common armature as to cause the receiver-pen rod to reproduce the motion of the transmitter pencil.

It will be noted that this principle is nearly identical with that of Gruhu's Telechipograph,[2] recently described in the technical press, the main differences being that the telechipograph writes upon a larger field and uses a beam of light, and photographic record instead of a pen with ink record.

Following the writing telegraph, Professor Elisha Gray constructed, at his Chicago laboratory, an instrument which wrote upon stationary paper, and which he called a telautograph. It

1. Wm. Maver, Jr., *American Telegraphy.*
2. *Scientific American*, August, 1903.

*Prepared by James Dixon, E.E., and read by him before t[illegible] Institute of Electrical Engineers, October 28th, 1904. Reprinted by special required four line wires and operated as follows: by means of cords and drums the motions of the transmitting stylus were resolved into two component rotary motions which were used to operate two mechanical interrupters in the primary circuits of two induction coils. The relations of the parts were such that a motion of the transmitting stylus amounting to one-fortieth of an inch caused a complete make-and-break at one or both of the interrupters.

The line currents were the impulses produced in the secondary circuits of the induction coils. These impulses passed over lines to two electromechanical escapements in the receiver. By means of cords and drums, their motions were combined and caused to act upon the receiver pen. By the use of relays and condensers and a local battery at each receiver, the paper was advanced when necessary and the pen lifted from and lowered to the paper. The mechanical difficulties met with in perfecting this instrument were very great, and in the apparatus exhibited at the World's Fair in Chicago in 1893 the escapement mechanism was brought to a perfection thought impossible of attainment only a short time before. The writing showed a saw-tooth or step-by-step character due to the action of the escapements. The instrument was abandoned on account of the number of line wires required, limited speed, numerous fine adjustments, and cost and difficulty of manufacture.

In 1893, while still working at the escapement device, Professor Gray patented a variable-current instrument,[1] using two line wires, which worked, in a general way, like the present telautograph. The motions of the transmitter pencil were resolved into two components which were used to vary two line currents, the variable resistances being carbon rods dipping into tubes of mercury. The receiver contained two D'Arsonval movements, to the moving elements of which the pen-arms were attached. Professor Gray never developed this instrument much beyond the laboratory stage, probably on account of his firm belief in the escapement type.

Foster Ritchie, at that time an assistant to Professor Gray, gave considerable attention to this patent and perfected an instru-

1. U. S. Patent 494,962, April 4, 1893.

ment based on it. He obtained a patent for improvements[1] and has produced an instrument that operates in a fairly satisfactory manner[2] under certain favorable conditions.

The telautograph has been brought to its present state chiefly through experimental work done by, or under the personal direction of, Mr. George L. Tiffany, to whom several patents[3] for improvements have been granted. Mr. Tiffany's instrument operates upon the variable-current principle and includes a number of interesting features, among them what may be called a straight-line D'Arsonval movement, which is used to operate the receiver.

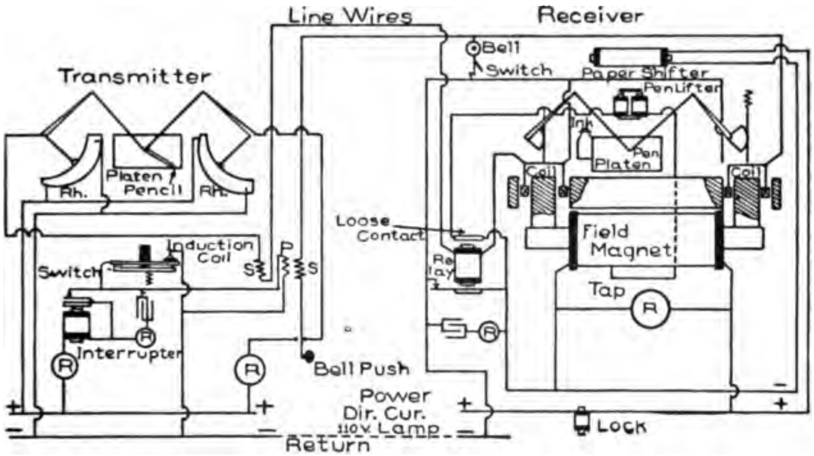


Fig. 1.

The operation may be briefly described thus: at the transmitter a pencil is attached by rods to two lever-arms which carry contact-rollers at their ends. These rollers bear against the surfaces of two current-carrying rheostats, connected to a constant-pressure source of direct current. The writing currents pass from the rheostats to the rollers and from them to the line wires. When the pencil is moved, as in writing, the positions of the rollers upon the rheostats are changed, and currents of varying strength go out upon the line wires. At the receiver these currents pass through two vertically movable coils, suspended by springs in magnetic

1. U. S. Pat. 656,828, Aug. 28, 1900.
2. *Elec. World and Engineer*, Dec. 8, 1900, Vol. XXXVI., No. 23.
3. U. S. Patents 668,889 to 668,895 inclusive, Feb. 26, 1901.

fields, and the coils move up or down according to the strengths of the line currents. The motions of the coils are communicated to levers similar to those at the transmitter, and on these levers is mounted the receiver pen, which, by the motions of the coils, is caused to duplicate the motions of the sending pencil. Fig. 1 shows the circuits of the instrument.

Many of the principles and devices in the instruments are of considerable interest. The method by which the variable currents are obtained is the laboratory arrangement for securing a variable pressure from a direct-current, constant-pressure circuit; that is, the line circuit (of constant resistance) is connected as a shunt around that part of the rheostat between the moving roller and the ground or return. Motion of the roller varies the amount of resistance in series with the line and also the amount in parallel with it and fine gradations are easily obtained, giving smooth motion of the receiver pen. In this way a variable pressure is impressed on the line circuit, giving a variable current. In all the other variable-current instruments, a constant pressure was impressed on the line and a resistance in series with the line varied to give the desired variations in current. One result of the shunting method is a better form of rheostat, more easy of construction and handling, in which, also, the heating is better distributed.

The rheostats are wound upon castings of I cross-section, with the turns of wire lying close together on the inner or contact-face. After winding, the insulation on this face is saturated with glue, which is allowed to harden and is then scraped off, taking the insulation with it, and giving a surface where contact is possible on every turn of the wire. This gives a rheostat of a large number of small steps, of good mechanical construction, and of low cost.

The receiver operates with what may be called a straight-line d'Arsonval movement. The moving element or coil is wound upon a copper shell for damping effect. The magnetic circuit is so arranged that one pole surrounds the other, forming an annular air-gap of short length and large cross-section in which the direction of the flux is radial. The field is electromagnetic and is highly excited, to secure uniformity. The coil, suspended in the annular space, moves up or down with little friction, as it touches the sides of the space of the core very lightly if at all. The principle is the well-known one that a current-carrying coil, in a magnetic field, tends to place itself with respect to the field so that the flux enclosed by the coil shall be a maximum.

The current for operating is taken from the ordinary lighting mains, preferably at about 115 volts. Satisfactory operation has resulted with pressures from 80 up to 250. At 115 volts, receiver and transmitter each require about one ampere while in operation. Fairly steady pressure is necessary as the receiver, being in effect a voltmeter, is rather sensitive to sudden changes, the effect being slight distortion of the message.

A master-switch at the transmitter is provided to do all necessary switching of line and power circuits, to make needed changes in connections and to cut off current when not writing. A relay in one of the lines closes the power circuit of the receiver whenever the transmitter at the distant station is switched on, and serves to prevent waste of current when not in operation.

Attached to the master-switch is a mechanical device which shifts the transmitter paper the space of one line of ordinary writing for each stroke of the switch. The relay mentioned controls the electrical receiver paper shifter and, as each stroke of the switch causes a stroke of the relay, the receiver paper is shifted an amount equal to that at the transmitter. The writing space is about two inches long and five inches wide, allowing for three or four lines of writing. When filled by messages, a few strokes of the switch serve to bring fresh paper into position at both receiver and transmitter.

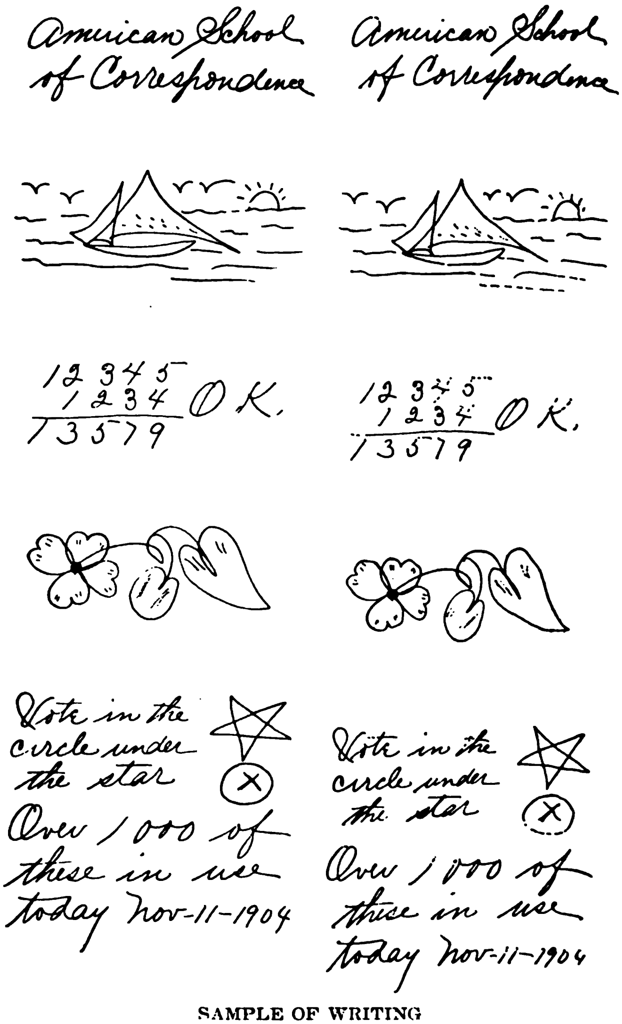
To prevent switching on of the transmitter while its home receiver is receiving a message from the distant station, an electromagnet lock is connected in the receiver power circuit, controlled by the relay, which locks the home transmitter in the "off" position until the distant transmitter is switched off. If both transmitters were switched on at once, neither station would receive any message; the lock is provided to render this condition impossible.

The ink supply is most important, and is arranged for as follows: at the left of the receiver platen is a bottle with a hole in the front near the bottom. When filled with ink and tightly corked the ink does not run out of this hole because of the pressure of the atmosphere. The ink is accessible for the pen at the hole and the surface of ink exposed to evaporation is small.

The pen is made of a piece of German silver bent double, after the manner of a ruling pen, and makes a uniform line in any direction over the paper. It takes up its supply by capillary attraction, from the hole in the front of the bottle. When the receiver is switched off, retractile springs draw the pen-arms to stops so arranged as to bring the pen exactly in front of the hole in the bottle, and when the pen-lifter armature is released the pen is caused to insert its tip in the opening. Thus a fresh filling of ink is obtained each time the paper is shifted. When not in use the pen rests in the ink, always ready to write.

For the prevention of mechanical shocks to the necessarily light moving system of the receiver, it has been necessary to supply means to prevent the switching on or off of the transmitter, and by that action of the receiver, when the transmitter pencil is "out in the field"; that is, at a position other than that corresponding to the opening in the receiver ink-bottle; as in that case the receiver pen would instantly jump to a similar position. This position is called the "unison point," a term having its origin in the days of the "self-propellor" escapement telautograph. By placing a catch, released only by pressure of the pencil-point upon it, at the transmitter unison point, the desired result is accomplished and the transmitter master-switch can not be switched either "off" or "on" unless the pencil be placed at the unison point and held there until the stroke of the switch is completed. In this case, as everywhere, the apparatus is made strong enough to stand any possible shocks, although every precaution is taken to prevent their occurrence. Aside from the shock to the moving system these jumps might shake the ink supply out of the pen and prevent the recording of the message.

The pen-lifter is a magnet placed back of the receiver writing platen, and carrying upon its armature a rod adapted to engage with the pen-arm rods and raise the pen clear of the paper when the magnet is energized. This magnet is controlled from the transmitter as follows: beneath the transmitter platen is a spring-contact, opened by pressure of the pencil upon the paper, and closed by a spring when the pencil is raised. An induction coil having an interrupter in its primary circuit is so connected to this spring-contact that when the pencil is raised the primary winding is short-circuited. The induction coil has two independent sec-



SAMPLE OF WRITING
Made especially for the American School of Correspondence over a distance of about 20 miles. At the left is shown the original, at the right the reproduction.

ondary windings through which the two variable line currents pass before leaving the transmitter. The effect of the induction coil and its interrupted primary current is to induce, in the two line currents, superimposed vibrations or "ripples" when the pencil is pressed down on the paper and the spring-contact is open. When the contact is closed, by its spring, and the primary winding is cut out, no vibrations are produced in the line currents. In one of the line wires, at the receiver, is placed a relay upon whose sheet-iron diaphragm armature is mounted a loose contact, consisting of two platinum-silver contacts in series, sealed in a glass tube, to prevent oxidation. A local circuit contains the winding of the pen-lifter magnet and this loose contact.

When the vibrations are present in the line current, due to the pressure of the pencil upon the paper and consequent opening of short circuit of the primary of the induction coil, the diaphragm of the relay is shaken, the loose contact opened, and the pen-lifter de-energized, its armature being drawn back by a spring and the pen being allowed to rest against the paper. When there are no vibrations in the line currents due to the raising of the pencil from the paper, the relay diaphragm is at rest, the pen-lifter is energized, and the pen is lifted clear of the paper.

The superimposed vibrations used for operating the pen-lifter have another minor effect. The suspended coils, and through them the entire moving system of the receiver, are kept in a state of very slight mechanical vibration while the pen is on the paper. This aids the flow of ink from the pen-point, assists the pen in passing over any roughness or irregularity in the surface of the paper, and materially reduces friction in the joints and pivots of the moving system, and results in better writing. In some of the later instruments, the two relays, that for pen-lifting and that for paper-shifting and power-switching, are combined in a single piece of apparatus.

For signaling, a push-button is placed upon the transmitter and a call-bell or buzzer is mounted on the receiver. This circuit is disconnected by the master-switch while a message is being written. Spring reels are attached when needed to roll up the received messages for preservation and future reference.

The ordinary arrangements for operation are as follows: the instruments may be operated singly, upon a private line having an instrument at each end, or on an exchange system where a switchboard provides for connection. Working in this way, satisfactory writing has been obtained with a resistance in each line wire of 1,600 ohms and an operating pressure of 110 volts. Multiple operation can be carried out to a limited extent, three receivers being at present the maximum number that can be operated at once, in multiple, using 110 volts. This allows of placing a supervisory machine upon a line.

When no response to messages beyond a bell signal is required, and the same message is to be sent to a number of stations, a series

Fig. 2.

arrangement of receivers is used. With a transmitting pressure of 110 volts a maximum of seven receivers can be operated from a single pair of transmitting rheostats and rollers. This number may be increased by increasing the pressure or by adding additional rheostats and rollers, operated by the same pencil. Using both these methods a maximum of 50 or more receivers may be operated at once.

Instances in actual commercial use of the arrangements of instruments mentioned are: private lines; the transmission of mail and other orders from office to factory or yards; investigation of checks over lines between paying tellers and bookkeepers in banking concerns, and transmission of messages, usually in cipher, between brokerage firms and cable or telegraph offices. A few moments' thought will bring to mind many places where a telautograph private line could be used to save time and trouble, especially where accurate transmission of figures is essential.

Multiple operation may be resorted to when a third station upon a line desires a record, accessible at any time, of what is being sent, as, for instance, when one of the officers of a bank desires to know what passes between his bookkeepers and paying tellers. On such a line the third station receives all messages and can write to either or both of the other stations, should the necessity arise.

Series operation may be used when several stations are to receive the same message and no response except a bell signal is required, as in sending orders in a hotel or club from dining room to kitchen, pantry and wine room; in "reporting" or news service, or for bulletin work, such as the announcement of arrival and departure of trains to a number of stations in a large railway station or freight depot. Fig. 2 shows the standard commercial instrument.

One of the most important uses for series systems has been found in the U. S. Coast Defense Service, in sending ballistic data, such as range and azimuth of target, or character of projectile, from position-finding stations to the gunners. This is called "fire-control communication" and is installed in the forts by the U. S. Signal Corps. In a paper presented by Col. Samuel Reber on "Electricity in the Signal Corps,"[1] will be found a description of the position-finding systems. The desired characteristics of a system of communication for sending this data to the guns are stated as follows:

> "The system that will successfully solve this problem must be simple in construction, mechanically strong so as not to be affected by the blast, as the receivers are placed close to the guns, rapid in operation, and give a character of record that can be read without liability of error."

Since that paper was prepared, it has been decided that the receivers must be mounted directly on the gun-carriage and can have no shelter other than that afforded by their own cases. Add to these requirements the facts that the instruments must be cared for by post electricians, and operated by enlisted artillerymen; that messages must be visible at night; and the operation must be

1. TRANSACTIONS, A. I. E. E., Vol. XIX., pp. 723 and 724.

independent of rain, salt mists, cold, heat, or tropical insects, and it is apparent that no easy problem is presented.

A special type of telautograph has been designed for this service and has been adopted by the U. S. Signal Corps[1] for fire-control communication.

In this service "telautograph," the rather delicate pen-lifter

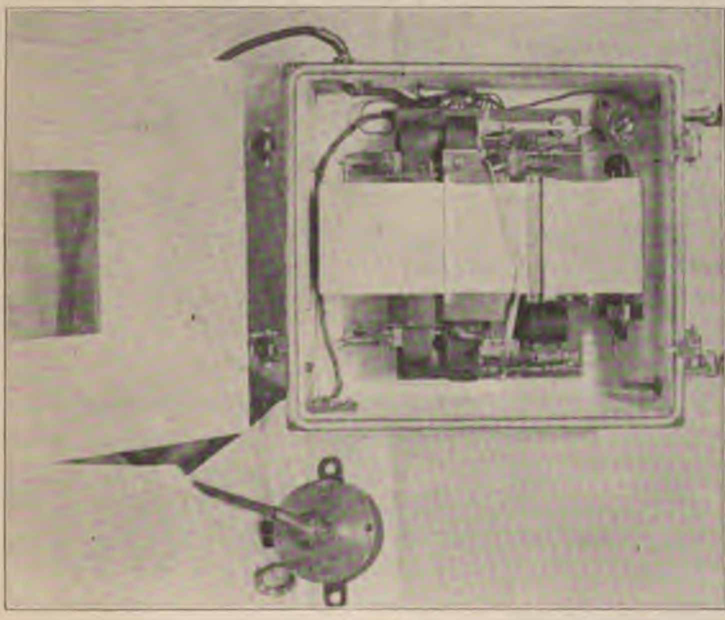


Fig. 3.

relay is eliminated and the receiver pen-lifters are operated over a third line wire by the transmitter platen switch directly.

Each gun receiver is enclosed in a water-tight brass case, suspended by springs from the gun carriage directly in front of the gunner. The parts are as far as possible made "brutally strong," and the construction is as simple as possible.

The desired rapidity of operation is inherent to the telautograph, and accuracy of record is ensured by careful writing and by the use of a "home" receiver, mounted at the transmitter where the operator can see it plainly, which is connected in series with

1. TRANSACTIONS, A. I. E. E., Vol. XIX., p. 673.

the gun receivers and records the messages as actually sent over the line.

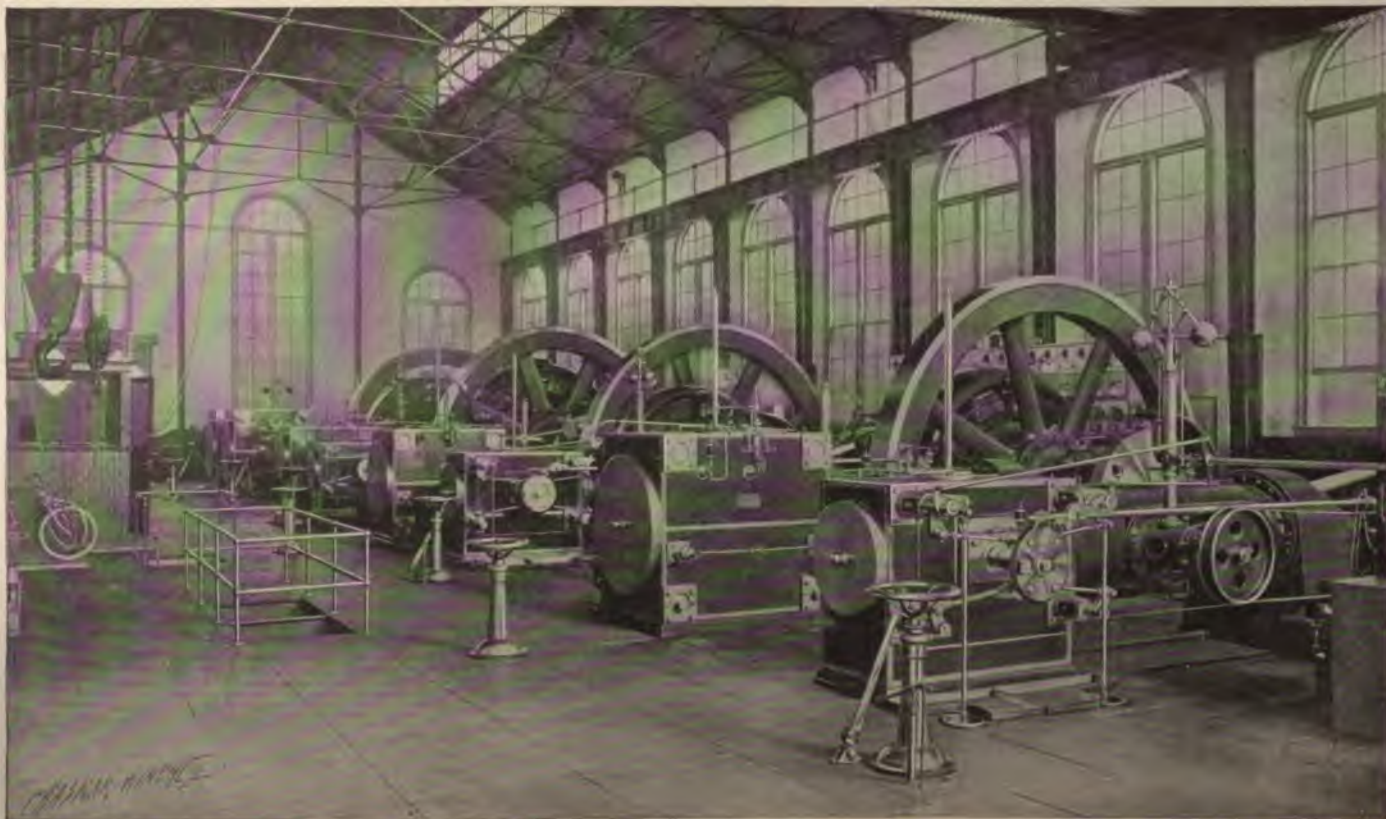
Freezing of ink is prevented by the addition of alcohol; and rain, mists, and insects, as well as the effects of the blast, are shut out by the metal case. A heavy glass window is placed in the case so that messages can be read without opening the case.

A small incandescent lamp inside the case lights automatically when the receiver is writing and may be lighted by pressing a button at other times, thus providing for visibility at night. Fig. 3 shows the army type of receiver mounting.

On warships there is a somewhat similar service to be rendered and the performance of this should fall to the army type of telautograph.

Commercial service has given opportunity for the installation of a considerable number of private line telautographs in actual use, and at least three of each of the other typical installations are in operation at the present time.

Much of the improvement in details of construction and reliability in operation has resulted from experience gained in efforts to perfect the service of these commercial plants. The experience leading up to the special army type of telautograph has extended over a period of about five years and in the present instrument all the requirements, unusually severe as they are, have been successfully fulfilled.



CROSS-COMPOUND CONDENSING CORLISS ENGINES.

Direct-Connected to Electric Railway Generators.

INSULATORS FOR TRANSMISSION LINES.

Line insulators, pins, and cross-arms all go to make up paths of more or less conductivity between the wires of a transmission circuit. The amount of current flowing along these paths from one conductor to another in any case will depend on the combined resistance of the insulators, pins, and cross-arm at each pole.

As a general rule, the wires of high-voltage transmission circuits are used bare because continuous coverings would add materially to the cost with only a trifling increase in effective insulation against high voltages. In some instances the wires of high-pressure transmission lines have individual coverings for short distances where they enter large cities, but often this is not the case. At Manchester, New Hampshire, bare conductors from water-power plants enter the substation, well within the city limits, at 12,000 volts. From the water power at Chambly the bare 25,000-volt circuits, after crossing the St. Lawrence River over the great Victoria Bridge, pass overhead to a terminal house near the water front in Montreal. In order to reach the General Electric Works, the 30,000-volt circuits from Spier Falls enter the city limits of Schenectady, New York, with bare overhead conductors.

Where transmission lines pass over a territory exposed to corrosive gases, it is sometimes desirable to give each wire a weatherproof covering. An instance of this sort occurs near Niagara Falls where the aluminum conductors forming one of the circuits to Buffalo are covered with a braid that is saturated with asphaltum.

Each path, formed by the surface of the insulators of a line and the pins and cross-arm by which they are supported, not only wastes the energy represented by the leakage current passing over it, but may lead to the charring and burning of the pins and cross-arm by this current. To prevent such burning, the main reliance is to be placed in the surface resistance of the insulators rather than that of pins and cross-arms. These insulators should be made of glass or porcelain, as far as past experience is a guide, and should be used dry, that is, without oil. In some [illegible] early transmission lines, insulators were used on which the lower edges were turned inward and upward so that a circular trough was formed beneath the body of the insulator, and this trough was filled with heavy petroleum. It was found, however, that this trough of oil served to collect dirt and thus tended to lower the insulation between wire and cross-arm, so that the practice was soon abandoned. Glass and porcelain insulators are rivals for use on high-tension lines and each has advantages of its own. Porcelain insulators are much stronger mechanically than are those of glass, and are not liable to crack because of unequal internal expansion, a result sometimes met with where glass insulators are exposed to a hot morning sun. In favor of glass insulators it may be said that their insulating properties are quite uniform, and that, unlike porcelain, their internal defects are generally apparent on inspection. In order to avoid internal defects in large porcelain insulators, it has been found necessary to manufacture some designs in several parts, and then cement the parts of each insulator together.

Defective insulators may be divided into two classes—those that the line voltage will puncture and break, and those that permit an excessive amount of current to pass over their surfaces to the pins and cross-arms. Where an insulator is punctured and broken, the pin, cross-arm, and pole to which it is attached, are liable to be burned up. If the leakage of current over the surface of an insulator is large, not only may the loss of energy on the line where the insulator is used be serious, but this energy follows the pins and cross-arm in its path from wire to wire, and gradually chars the former, or both, so that they are ultimately set on fire or break through lack of mechanical strength. The discharge over the surface of an insulator may be so large in amount as to have a disruptive character, and thus to be readily visible. More frequently this surface leakage of current over insulators is of the invisible and silent sort that nevertheless may be sufficient in amount to char, weaken, and even ultimately set fire to pins and cross-arms.

All insulators, whether made of glass or porcelain, should be tested electrically to determine their ability to resist puncture, and to hold back the surface leakage of current, before they are put into practical use on high-tension lines. Experience has shown that inspection alone cannot be depended on to detect defective glass insulators that will fail when put into service on high-voltage lines. Electrical testing of insulators serves well to determine the voltage to which they may be subjected in practical service with little danger of puncture by the disruptive passage of current

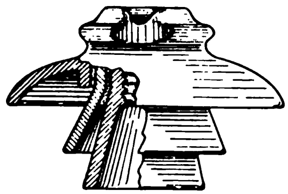
INSULATOR. ARC TO METAL PIN AT 96,000 VOLTS.
Precipitation ¾ inch per minute. Diameter 14".
30° above horizontal. Height 12".
Duration of test, 15 minutes. Weight 22 lbs.

through their substance. It is also possible to determine the voltage that will cause a disruptive discharge of current over the surface of an insulator, when the outer part of this surface is either wet or dry. This is as far as electrical tests are usually carried, but it seems desirable that such tests should also determine the amount of silent, invisible leakage over the surface of insulators both when they are wet and when they are dry, at the voltage which their circuits are intended to carry. Such a test of silent leakage is important because this sort of leakage chars and weakens insulator pins, and sets fire to them and cross-arms, besides representing a waste of energy.

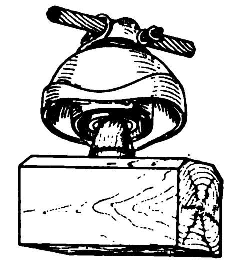
The voltage employed to test insulators should vary in amount according to the purpose for which any particular test is made. Glass and porcelain, like many other solid insulators, will withstand a voltage during a few minutes that will cause a puncture if continued indefinitely. In this respect these insulators are unlike air, which allows a disruptive discharge at once when the voltage to which it is exposed reaches an amount that the air cannot permanently withstand. Because of this property of glass and porcelain insulators, it is necessary in making a puncture test, to employ a voltage much higher than that to which they are to be permanently exposed. In good practice it is thought desirable to test insulators for puncture with at least twice the voltage of the circuits which they will be required to permanently support on transmission lines.

For the first transmission line from Niagara Falls to Buffalo, which was designed to operate at 11,000 volts, the porcelain insulators were tested for puncture with a voltage of 40,000, or nearly four times that of the circuits they were to support.

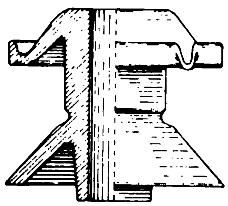
Porcelain insulators for the second line between Niagara Falls and Buffalo, after the voltage of transmission had been raised to 22,000, were given a puncture test at 60,000 volts. Of these insulators tested at 60,000 volts only about 3 per cent proved to be defective. These puncture tests were carried out by placing each insulator upside down in an open pan containing salt water to a depth of two inches, partly filling the pin hole of the insulator with salt water, and then connecting one terminal of the testing circuit with a rod of metal in the pin hole, and the other terminal with the pan. Alternating current was employed in these tests, as is usually the case, and they are mentioned in Volume XVIII, Transactions A.I.E.E., pages 514 to 520. For the transmission lines between Spier Falls, Schenectady, Albany, and Troy, where the



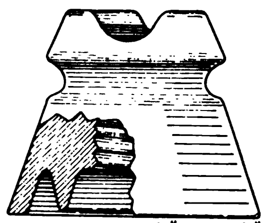
3 PIECE INSULATOR.
20,000 TO 80,000 VOLTS



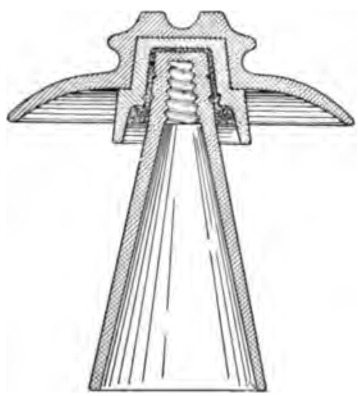
THE NIAGARA TYPE OF
PORCELAIN INSULATOR.



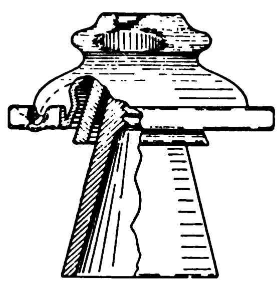
STRAIN INSULATOR FOR
DEAD ENDS AND CORNERS.



FOR CABLES ½" TO 2¼"
DIAMETER.



20,000 TO 80,000 VOLTS.



SHOWING EAVE TROUGHS.

voltage is 30,000 the insulators were required to withstand a puncturing test with 75,000 volts for a period of five minutes, after they had been soaked in water for 24 hours.

There is some difference of opinion as to the proper duration of a puncturing test, the practice in some cases being to continue the test for only one minute on each insulator, while in other cases the time runs up to five minutes or more. As a rule, the higher the testing voltage compared with that under which the insulators will be regularly used, the shorter should be the period of test. Instead of being tested in salt water as above described, an insulator may be screwed onto an iron pin of a size that fits its threads, and then one side of the testing circuit put in contact with the pin, and the other side connected with the wire groove of the insulator. Care should be taken where an iron pin is used either in testing or for regular line work, that the pin is not screwed hard up against the top of the insulator, as this tends to crack off the top, especially when the pin and insulator are raised in temperature. Iron expands at a much higher rate than glass or porcelain, and it is desirable, where an iron pin is screwed into the insulator, to place a washer of leather or cork over the top of the pin so that the iron will not press hard against the inside of the insulator top. In this way a little room for expansion is provided by compression of the washer. There seems to be some reason to think that an insula-

Transformer Discharging Through a 32-in. Gap.

tor will puncture more readily when it is exposed to severe mechanical stress by the expansion of the iron pin on which it is mounted.

Tests of insulators are usually made with alternating current, and the form of the voltage curve is important, especially where the test is made to determine what voltage will arc over the surface of the insulator from the line wire to the pin. The square root of the mean square for two curves of alternating voltage, as read by a voltmeter, may be the same though the maximum voltages of the two curves differ widely. In tests for the puncture of insulators, the average alternating voltage applied is more important than the maximum voltage shown by the highest points of the pressure curve, because of the influence of the time element with glass and porcelain. On the other hand, when the test is to determine the average voltage at which current will arc over the insulator surface from the line wire to the pin, the maximum value of the pressure curve should be taken into consideration because air has no time element, but permits a disruptive discharge under a merely instantaneous voltage.

Transformer Discharging Through and Around a Heavy Glass Plate.

Alternators used in transmission systems usually conform approximately to a sine curve in the instantaneous values of the pressures they develop, and it is therefore desirable that tests on line insulators be made with voltages whose values follow the sine curve. Either a single transformer or several transformers in series may be employed to step up to the required voltage, but a single transformer will usually give better regulation and greater accuracy. An air gap between needle points is not a very satisfactory means by which to determine the average voltage on a testing circuit, because, as already pointed out, the sparking distance between the needle points depends mainly on the maximum instantaneous values of the voltage, which may vary with the load on the generator and the saturation of its magnets. For accurate results a step-down voltmeter transformer should be used on the testing circuit.

Transformer Discharging Between Sheets of Tinfoil Around a Glass Plate.

An insulator that resists a puncture test perfectly may fail badly when subjected to a test as to the voltage that will arc over its surface from line-wire to pin. This arc-over test should be made with the outer surface of the insulator both wet and dry. For the purpose of this test the insulator should be screwed onto an iron pin, or onto a wooden pin that has been covered with tinfoil. One wire of the testing circuit should then be secured in the groove of the insulator, which should preferably be on top, and the other wire should be connected to the iron or tinfoil of the pin. The voltage that will arc over the surface of an insulator from the line wire to the pin depends on the conditions of that surface and of the air. In light air, such as is found at great elevations, an arc will jump a greater distance than in dry air near the sea level. A fog increases the distance that a given voltage will jump between a line-wire and its insulation pin, and a heavy rain lengthens the distance still further. The heavier the downpour of rain the greater is the distance over the outside surface of an insulator that a given voltage will arc over. The angle at which the falling water strikes the insulator surface also has an influence on the voltage required to arc over that surface, a deviation from a downpour perpendicular to the plane of the lower edge of the petticoat of the insulator seeming to increase the arcing distance for a given voltage.

An insulator should be given an arc-over test under conditions that are approximately the most severe to be met in practice. These conditions can perhaps be fairly represented by a downpour of water that amounts to a depth of one inch in five minutes for each square inch of the plane included by the edge of the largest petticoat of the insulator, when the direction of the falling water makes an angle of 45 degrees with that plane. A precipitation of one inch in depth on a horizontal plane during five minutes seems to be a little greater than any recorded by the United States Weather Bureau. Under the severe conditions just named, the voltage required to arc over the insulator surface from line-wire to pin should be somewhat greater at least than the normal voltage of the circuit where the insulator is to be used. For the transmission line between Spier Falls and Schenectady, on which the maximum voltage is 30,000, the insulators were required to stand a test of 42,000 volts when wet, without arcing over from line-wire to pin. In these wet tests the water should be sprayed evenly onto the insulator surface like rain, and the quantity of water that strikes the insulator, in a given time, should be measured.

When the outside of an insulator is wet, it is evident that most of the resistance between the line wire and the insulator pin must be offered by the inside surface of the petticoat of the insulator and by the air between the lower edge of the petticoat and the pin or cross-arm. For this reason an insulator that is to withstand a very high voltage so that no arc will be formed over its wet outside surface, must have not only a wide, dry surface under its petticoat, but also a long distance through the air between the lower wet edge of the insulator and the pin or cross-arm. In some tests of line insulators reported in Volume XX, Transactions A.I.E.E., pages 521 to 525, the results show that the voltage required to arc over from line-wire to pin depends on the shortest distance between them, rather than on the distance over the insulator surface. Three insulators, numbered 4, 5, and 7 in the trial, were in each case tested by a gradual increase of voltage until a discharge took place between the wire and pin. The pins were coated with tinfoil, and the testing voltage was applied to the tie wire on each insulator and to the tinfoil of its pin. Insulators 4, 5, and 7 permitted arcs from wire to pin when exposed to 73,800, 74,700, and 74,700 volts respectively, the surfaces of all being dry and clean. The shortest distances between wires and pins over insulator surface and through air were $6\frac{5}{8}$, $6\frac{1}{4}$, and $7\frac{7}{8}$ inches respectively for the three insulators, so that the arcing voltages amounted to 11,140, 11,952, and 9,479 per inch of these distances. Measured along their surfaces the distances between wires and pins on these three insulators were 8, $11\frac{1}{4}$, and $15\frac{1}{2}$ inches respectively, so that the three arcing voltages, which were nearly equal, amounted to 9,225, 6,640, and 4,819 per inch of these distances. These figures make it plain that the arcing voltage for each insulator depends on the shortest distance over its surface and through the air, from wire to pin. It might be expected that the voltage in any case would arc equal distances over clean, dry insulator surface or through the air, and the experiments just named indicate that this view is approximately correct. The sparking distance through air between needle points, which is greater than that between smooth surfaces, is 5.85 inches with 70,000 volts, and 7.1 inches with 80,000 volts according to the report in Volume XIX, A.I.E.E., page 721. Comparing these distances with the shortest distances between wires and pins in the tests of insulators numbered 4, 5, and 7, which broke down at 73,800 to 74,700 volts when dry, it seems that a given voltage will arc somewhat further over clean, dry ulator surface than it will through air. This view finds support n the fact that only a part of each of the shortest distances ween wire and pin was over insulator surface, the remainder ng through air alone.

The fact that the dry part of the surface of an insulator and the air between its lower wet edge and the pin or cross-arm offer most of the resistance between the line-wire and the pin and cross-arm, is plainly brought out by the results of the tests above mentioned, in the cases of insulators numbered 4 and 7. While 73,800 volts were required to arc from line wire to pin when the entire insulator was dry and clean, the arc was formed at only 53,400 volts during a moderate rain storm, in the case of number 4 insulator. With insulator number 7 the arcing voltage was 74,700 when the entire surface was clean and dry, but the arc from wire to pin was started with 52,800 volts during a moderate rain. Number 5 insulator seems to present an erratic result, for when dry and clean the arc jumped from wire to pin at 74,700 volts, and yet during a moderate rain no arc was formed until a voltage of 70,400 was reached. For each of the seven insulators on which tests are reported as above, the voltage required to arc from line-wire to pin was nearly or quite as great during a dry-snow storm as when the insulator surface was clean and dry. When the insulators were covered with wet snow their surface insulation broke down at voltages that were within 10 per cent above or below the arcing voltages during a moderate rain in five cases. With two insulators the arcing voltages, when they were covered with wet snow, were only about 60 per cent of the voltages necessary to break down the surface insulation between wire and pin during a moderate rain.

When the outside surface of an insulator is wet, as during a moderate rain, it seems that the under surface of the insulator, and the distance through air from the lower wet edge of the insulator to the pin or cross-arm, make up most of the insulation that prevents arcing over from the wire to the pin or cross-arm. It further appears that it is useless to extend the distance across the dry under surface of the insulator indefinitely without a corresponding increase of the direct distance through air from the lower wet edge of the insulator to the wood of cross-arm or pin. Insulator number 7 in the tests under consideration had a diameter at the lower edge of its outer petticoat of 7 inches, and was mounted on a standard wooden pin. The diameter of this pin in the plane of the lower edge of the insulator was probably about 1¼ inches, so that the radial distance through air from this edge to the pin must have been $2\frac{7}{8}$ inches approximately. During a moderate rain the surface insulation of this insulator broke down and an arc was formed from wire to pin with 52,800 volts. The sparking distance between needle points at 50,000 volts is 3.55 inches, according to Volume XIX A.I.E.E., page 721 and must be shorter between smooth surfaces, such as the wire and pin in question, so that nearly all of the 52,800 volts in this case must have been required to jump the $2\frac{7}{8}$ inches of air, leaving very little to overcome the slight resistance of the wet outside surface of the insulator. On this insulator the surface distance from wire to pin was $15\frac{1}{2}$ inches, while the shortest breaking distance was only $7\frac{7}{8}$ inches, so that the distance across the dry under surface of the insulator must have been $15\frac{1}{2} - (7\frac{7}{8} - 2\frac{7}{8}) = 10\frac{1}{2}$ inches approximately. It is evidently futile to put a path $10\frac{1}{2}$ inches long across dry insulator surface in parallel with a path only $2\frac{7}{8}$ inches long in air, as an arc will certainly jump this shorter path long before one will be formed over the longer. The same line of reasoning applies to number 3 insulator in this test, which had a diameter of $6\frac{3}{4}$ inches, a surface distance from wire to pin of 13 inches and a minimum distance of $7\frac{1}{4}$ inches, and whose surface insulation broke down at 48,600 volts during a moderate rain. The absolute necessity of increasing the distance between the lower wet edges of insulators and the pins and cross-arm, as well as the distance across the dry under surfaces of insulators, has led to the adoption of the so-called umbrella type for some high-voltage lines. In this type of insulator the main or outer petticoat is given a relatively great diameter, and instead of being bell-shaped is only moderately concave on its under side. With an insulator of this type mounted on a large, long pin, the lower edge of the umbrella-like petticoat may be far removed from the pin and cross-arm. Beneath the large petticoat of such insulators for high voltages there are usually one or more smaller petticoats or sleeves that run down over the pin, and increase the distance between it and the lower edge of the largest petticoat, if this distance is measured entirely through the air.

The inner petticoat or sleeve that runs down over the pin and sometimes reaches nearly to the cross-arm, of course becomes wet on its outside surface and at its lower edge during a rain, but

Insulators on Transmission Lines.

LOCATION OF LINE.	Voltage of Line.	Material of Insulator.	Inches Diameter of Insulator.	Inches Height of Insulator.
Electra to San Francisco	60,000	Porcelain	11	11¼
Colgate to Oakland, Cal.	60,000	Porcelain	11	11¼
Canon Ferry to Butte	50,000	Glass	9	12
Shawinigan Falls to Montreal	50,000	Porcelain	10	13
Provo around Utah Lake	40,000	Glass	7	5¾
Santa Ana River to Los Angeles	33,000	Porcelain	6¾	4⅞
Spier Falls to Schenectady	30,000	Porcelain	8½	6¾
Apple River Falls to St. Paul	25,000	Glass	7	5¾
Chambly to Montreal	25,000	Porcelain	5½	6½
Niagara Falls to Buffalo	22,000	Porcelain	7½	7
Portsmouth to Pelham, N. H.	13,000	Porcelain	5¼	3¾
Garvins Falls to Manchester, N. H.	12,000	Glass	5	4¾

between this lower wet part of the inner petticoat, or sleeve, and the lower wet edge of the larger outside petticoat, there is a wide, dry strip of insulator surface. A result is that an arc over the surface of the outside petticoat can only reach the wet edge of the sleeve by crossing the strip of dry under surface or jumping through the air.

The same type of insulator is used on the 60,000-volt lines between Electra and San Francisco, and between Colgate and Oakland, each insulator having an outer petticoat 11 inches diameter and one inner petticoat or sleeve 6½ inches diameter. This inner petticoat runs down the pin for a distance of 7½ inches below the outer petticoat. Slightly different pins are used for mounting

Insulators on Transmission Lines.

LOCATION OF LINE.	Inches from top of insulator to cross-arm.	Inches from outside petticoat to cross-arm.	Inches from lowest petticoat to cross-arm.	Inches from edge of outside to edge of lowest petticoat.
Electra to San Francisco	14½	11	3½	7½
Colgate to Oakland	15	11½	4	7½
Canon Ferry to Butte	13½	7¾	1½	6¼
Shawinigan to Montreal	16¼	11¾	3¼	8½
Santa Ana River to Los Angeles	8⅝	3¾	3¾	0
Spier Falls to Schenectady	10¾	7⅜	4¼	3⅜
Niagara Falls to Buffalo	10	5½	3	2½
Chambly to Montreal	8½	4½	2	2½

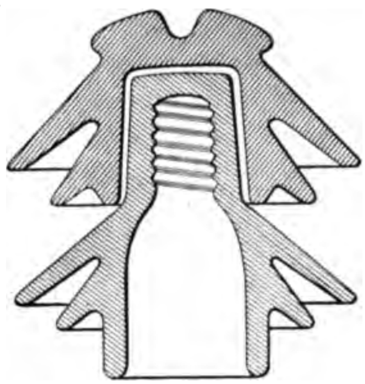
On each of the lines named in this table the wires are strung on the tops of their insulators.

the insulators on the two transmission lines just named, so that on the former the distance through air from the lower edge of the outer petticoat to the cross-arm is 11 inches, and on the latter the corresponding distance is 11½ inches. On the Electra line the lower edge of the inner petticoat of each insulator is about 3½ inches, and on the Colgate line about 4 inches above the cross-arm.

The Canon Ferry line is carried on insulators, each of which has three short petticoats, and a long separate sleeve that runs down over the pin to within 1½ inches of the cross-arm. This sleeve makes contact with its insulator near the pin hole and electrically may be considered a part of it. The outside petticoat of each insulator on this line is 7¾ inches above the cross-arm, and 6¼ inches above the lower end of the sleeve. Both the main insulator and the sleeve in this case are of glass.

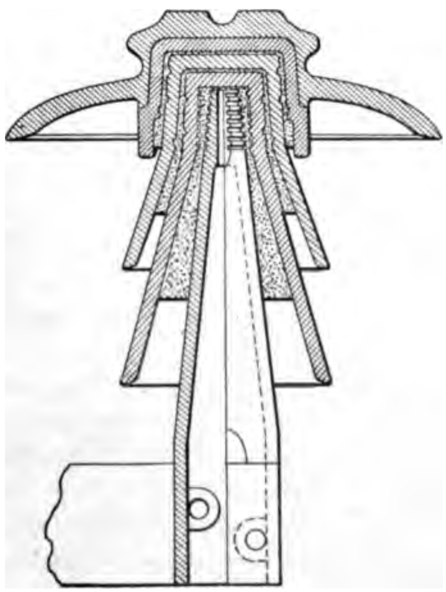
White porcelain insulators are used to support the 50,000-volt Shawinigan line and are of a design that has not come into general use elsewhere. Each of these insulators has three petticoats ranged about a central stem so that their lower edges are 4½ inches, 9 inches and 13 inches respectively, below the top. The highest petticoat is 10 inches, the intermediate 9¾ inches, and the lowest 4¼ inches in diameter. The height of this insulator is 13 inches, compared with 11¼ inches for those used on the Electra and Colgate lines, and 12 inches for the combined insulator and sleeve used on the Canon Ferry line. When mounted on its pin, this insulator on the Shawinigan line holds its wire 16¼ inches above the cross-arm, compared with a corresponding distance of 14½ inches on the Electra, 15 inches on the Colgate, and 13½ inches on the Canon Ferry line. The two upper petticoats on each of these insulators are much less concave than the lowest one, and the edges of all three stand respectively 11¾, 7¼, and 3¼ inches above the cross-arm. From the edge of the top to the edge of the bottom petticoat, the distance is 8½ inches.

Of the three transmission lines above named, that operate at 50 to 60 thousand volts, that between Shawinigan Falls and Montreal leads as to distances between the line-wire and insulator petticoats, and the cross-arm. On the Santa Ana line, where the voltage is 33,000, the insulator is of a more ordinary type, being of porcelain, 6¾ inches in diameter, 4⅞ inches high, and having the lower edges of its three petticoats in the same plane. Each of these insulators holds its wire 8⅝ inches above the cross-arm, and has all of its petticoats 3½ inches above the cross-arm. Unlike the

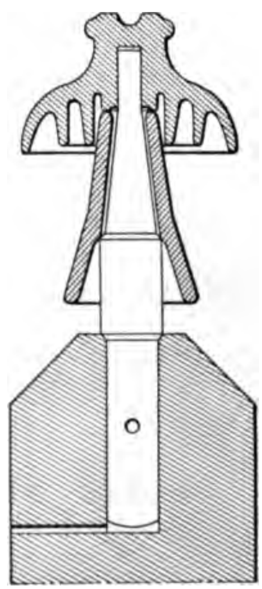


TWO PART INSULATOR
UP TO 30,000 VOLTS

PORCELAIN INSULATOR
WITH IRON PIN, BUILT UP.



60,000 VOLT INSULATOR
AND PIN.



GLASS INSULATOR FOR
55,000 VOLTS.

three insulators just described, which are mounted on wooden pins, this Santa Ana insulator has a pin with an iron core, wooden thread and porcelain base. This base extends up from the cross-arm a distance of $3\frac{1}{8}$ inches, and the wooden sleeve, in which the threads for the insulator are cut, runs down over the central bolt of the pin to the top of the porcelain base, which is $\frac{5}{8}$ inch below the petticoats.

The 30,000-volt lines from Spier Falls are carried $10\frac{3}{4}$ inches above their cross-arms by triple petticoat porcelain insulators. Each of these insulators is $8\frac{1}{2}$ inches in diameter, $6\frac{3}{4}$ inches high, and is built up of three parts cemented together. A malleable-iron pin cemented into each insulator with pure Portland cement carries with it the outside petticoat $7\frac{1}{8}$ inches, and its lowest petticoat $4\frac{1}{4}$ inches above the cross-arm. When the voltage on the Spier Falls lines was raised from about 13,000 to from 26,500 to 30,000, the circuits being carried in part by one-piece porcelain insulators, a number of these insulators were punctured at the higher pressures, and some cross-arms and poles were burned as a result. No failures resulted on those parts of these lines where the three-part insulators were in use. The second pole line between Niagara Falls and Buffalo was designed to carry circuits at 22,000 volts, or twice that for which the first line was built. Porcelain insulators were employed on both of these lines, but while the 11,000-volt line was carried on three-petticoat insulators, each with a diameter of 7 inches and a height of $5\frac{1}{2}$ inches, the 22,000-volt line was mounted on insulators each $7\frac{1}{2}$ inches in diameter and 7 inches high, with only two petticoats. The older insulator had its petticoats 2 inches above the cross-arm, and the lower petticoat of the new insulator is 3 inches above the arm. These two insulators illustrate the tendency to lengthen out along the insulator axis as the voltage of the circuits to be carried increases.

For future work at still higher voltages, the advantage as to both first cost and insulating qualities seems to lie with insulators that are very long in an axial direction, like those on the Shawinigan line, and which have their petticoats arranged one below the other and all of about the same diameter, rather than with insulators of the umbrella type, like those on the Electra and Colgate lines.

ELECTRIC WELDING DEVELOPMENT.

The art of welding iron is probably as old as the earliest production of that metal by man; in fact, the reduction of iron in the primitive forges demanded the union by welding of the reduced particles, for no true fusion could have resulted, the percentage of carbon present being too low. Until the closing years of the last century iron was the only weldable metal, if we except gold and platinum,—too expensive for common application.

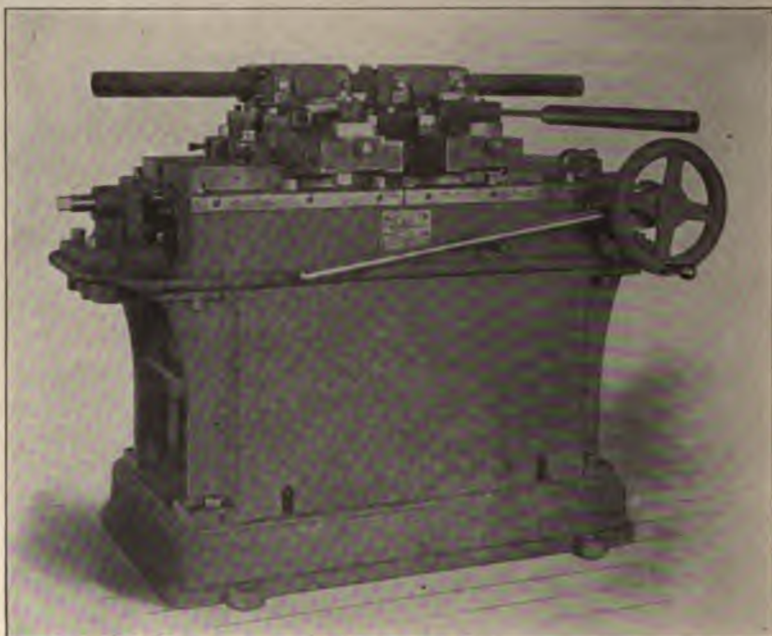
The fact that nearly pure iron, so difficult to melt, becomes quite plastic at high temperatures, while the oxide or black scale melts long before the metal itself becomes fluid, thus providing a liquid flux which is squeezed out during the process of union, accounts for the unique position which iron held until recent years. When, however, the heating effects of electric current energy, so perfectly under control, were applied to weld metals, a metal or alloy which would not weld became the exception, instead of the rule, as before. Much of the former work of the smithy fire is now accomplished by the electric welding transformer, and although many metals are easily manipulated by the electric process, iron, of course, still occupies, as ever, the principal place.

The electric weld is becoming a more and more important factor in many industries. During recent years the extension of its application has been steady, and each year has witnessed its entrance into new fields. Sometimes, indeed, new manufactures, or new ways of obtaining results have been based upon its use. The electric welds under consideration are the results of that operation of uniting two pieces of metal by what is known as the Thomson process, first brought out by the writer and rendered available in commercial practice a considerable number of years ago. The rapidity, flexibility, cleanliness, neatness, accuracy, and economy of the electric process has won for it such an important standing in the arts that many future extensions in its application are assured.

NOTE: This article by Prof. Elihu Thomson, the inventor of the system of Electric Welding, first appeared in Cassiers' Magazine, and is here reprinted by special permission.

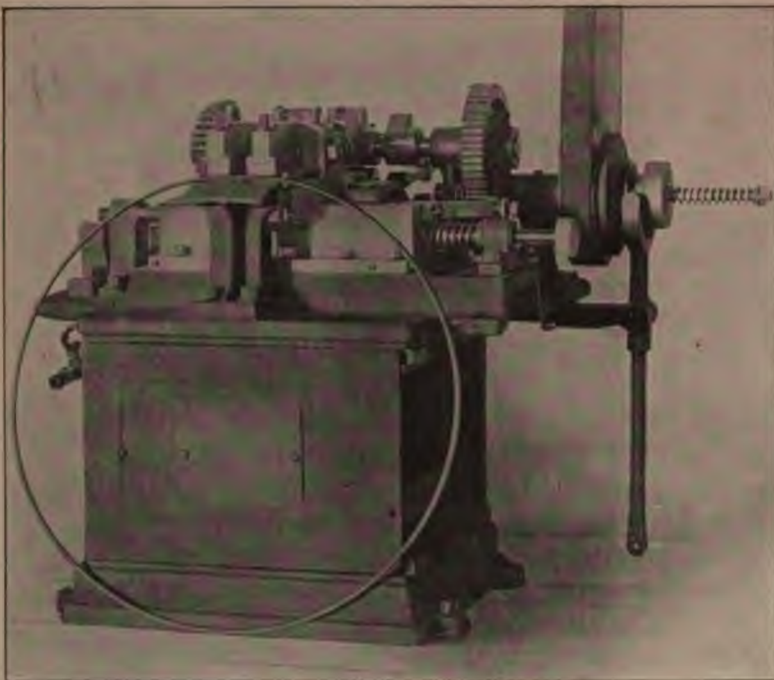
The uniformity of the work, the control of the operation, the extreme localisation of the heat to the particular parts to be united, and the fact that the process is not limited to iron and steel, but can deal equally well with other metals, such as copper, brass, bronzes, and even lead, are characteristics of the electric welding operation.

The Electric Welder. In its simplest form, an electric welder consists of a special transformer, the primary circuit of



ELECTRIC WELDING MACHINE FOR IRON AND STEEL PIPE.

which receives current from an electric station or dynamo generator, at a voltage usually from one hundred to five hundred times that required to make a weld. The copper secondary circuit of the transformer is generally only a single turn of very large section, so that it may develop an extremely heavy current at from two to four volts,—an electric pressure so low that it cannot give the least effect of shock, and one for which there is no difficulty in securing perfect insulation. The work pieces are held in clamps or vises, attached to or carried upon the terminals of the



ELECTRIC TIRE-WELDING MACHINE.

single-turn secondary circuit. The control of the clamping devices and the current switch is either manual, or, in some cases, entirely automatic. Without attempting to enumerate the many applications of electric welding in the arts, we may refer to a few examples.

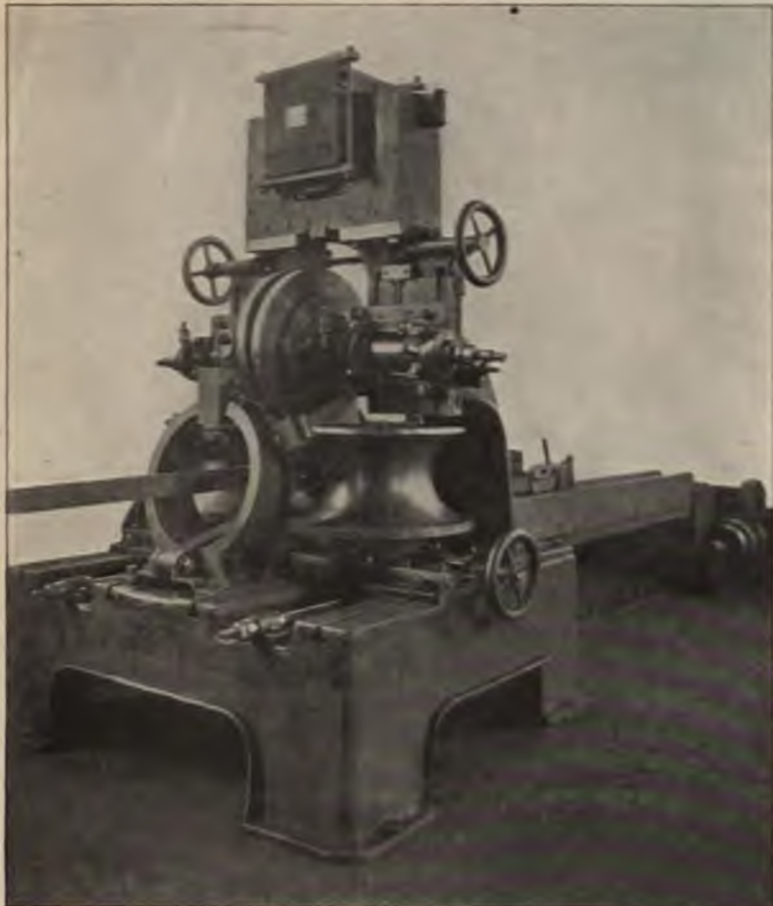
Applications. In the waggon and carriage industry the process is applied in the production of tires of all sections, axles, hub, spoke and sand bands, fifth wheels, shifting rails, steps, shaft iron, etc., while it has found a large use in the welding into continuous strips or bands of the wires inclosed in rubber tires for holding them in place. The larger part of the dash-frames used in carriages in the United States are now probably made by electric welding, while iron and steel agricultural wheels are built up, or have their parts united, by electric welds.

To enumerate the many applications to the bicycle industry would be almost to catalogue most of the metal parts of this useful machine. It must be borne in mind, too, that a welding machine, slightly modified, is equally applicable for locally heating parts in electric brazing or hard soldering, for upsetting, and for bending or shaping. Bicycle crank hangers, pedals, seat-posts, fork and fork ends, frames and brake parts thus become products in which the welding transformer has its part. It has found a useful field also in tool manufacture, such as drills, reamers, taps, band and circular saws, drawing knives, carpenter's squares, printer's chases, etc., etc., and electric welding has a closely related use in the production of machine parts. Cam shafts and crankshafts are made from drop forgings welded together, teeth are inserted into gear wheels, and teeth are welded to saw bodies, including stone saws. Such things as inking rolls in printing machines and fallers for looms are additional examples.

In the wire industry the part played by electric welding is already quite important, and becomes steadily more so. Besides the mere simple joining of wires of iron, steel or copper into long lengths, the welding of wire or strip into hoops for barrels, tubs, pails, etc., is supplanting the older forms. Numerous machines are in operation turning out electrically-welded wire fence, much as a loom turns out cloth. In pipe bending and coiling, as in uniting ordinary lengths of pipe into very long lengths without screw joints, the electric weld has a special adaptability. Hundreds of miles of street railway rails have been welded into continuous lengths and now exist in many cities. Where rails are bonded only, the electric welder assists in the production of brazed or welded bonds.

It is a wide range between buckles, typewriter bars and umbrella rods to the local annealing of armour plates on warships, but the electric welder covers that range. It is no wider, however, than that from fine wires of a diameter of one-fiftieth of an inch up to heavy steel wire for the armour of submarine cables, and again up to street railway rail joints.

In recent years, elaborate machinery, for the actual production on a large scale of steel tubing from flat stock or skelp by the progressive welding of a longitudinal seam, has been put into operation. The long strip, or skelp, is rolled up so that its edges meet. In this condition it enters between the welding rolls, which



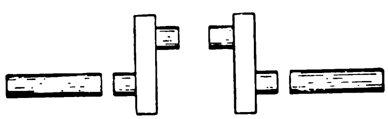
WELDING MACHINE FOR LARGE TUBES OR SHELLS UP TO 16 INCHES IN DIAMETER.

pass the heating current locally across the edges to weld them, and the operation is progressive from one end of the pipe to the other as it is fed into the machine. The result is a pipe of which the walls are of even thickness and the diameter uniform. This pipe can be afterward drawn, if needed, to the exact size desired. Very thin pipe can be made of steel, the longitudinal seam or weld in which is a delicate bead along the length,—a beautiful product, for the extreme localisation of the heat has allowed preservation of surface and finish of the metal outside the joint. Taper tubes, such as are used for bicycle front forks and the like, are easily made.

A similar machine for large work has lately been constructed, and by its use large diameter tubes or shells, up to 16 inches in diameter, are produced from sheet steel or iron. The accompanying illustration shows such a machine ready for operation. The welding transformer is at the top of the machine, and the secondary circuit has for its terminals two copper rolls inclined to each other on two nearly horizontal shafts adjustable in position over the work. Below are the guide rolls, one on each side on vertical shafts, and between these the shell to be welded passes with its meeting edges uppermost and in contact with the copper contact rolls. As the metal shell passes along under these rolls the joint is progressively heated by the welding current crossing it, and the weld is finished by the side pressure of the guiding rolls. The process, as well as the resulting welded product, is unique.

For a considerable time past, welding machines have been applied to the production of bands or tires from stock of varying width, thickness, and sectional form. More recently the practice of welding plain bands or cylindrical rings, and afterwards rolling them with the form of section desired, has been largely adopted; such as, for example, in the production of automobile wheel rims, bands for roving cans, stove rings, etc.

Very different from this is the formation of crankshafts, now demanded in great numbers for engines of automobiles. These are made from drop forgings and round shaft stock by uniting the pieces, as in the annexed sketch, and afterwards lightly machining and finishing the approximately correct shaft, as produced by welding.



Besides the banding of wire or strip of such comparatively frail containing vessels as barrels or pails, the electric weld finds application in the forming and capping of metal vessels for withstanding high pressures, such as soda-water cylinders, carbonic acid reservoirs, and steel bottles for nitrous oxide gas.

One of the most interesting of the more recent applications is that of welding hollow steel handles on cutlery, such as table

ELECTRIC RAIL WELDING ON STREET RAILWAYS.

knives and forks. The operation is remarkable for the celerity and neatness of the work, the articles being finished by silver-plating and polishing, as usual. The hollow handle is drawn from thin steel, and united to the knife blade or to the fork, as the case may be, in a special welding machine, there being no brazing or other operation of joint-forming required. There is, indeed, no limit to the delicacy of the work which may be undertaken, provided only the welding apparatus is equally refined.

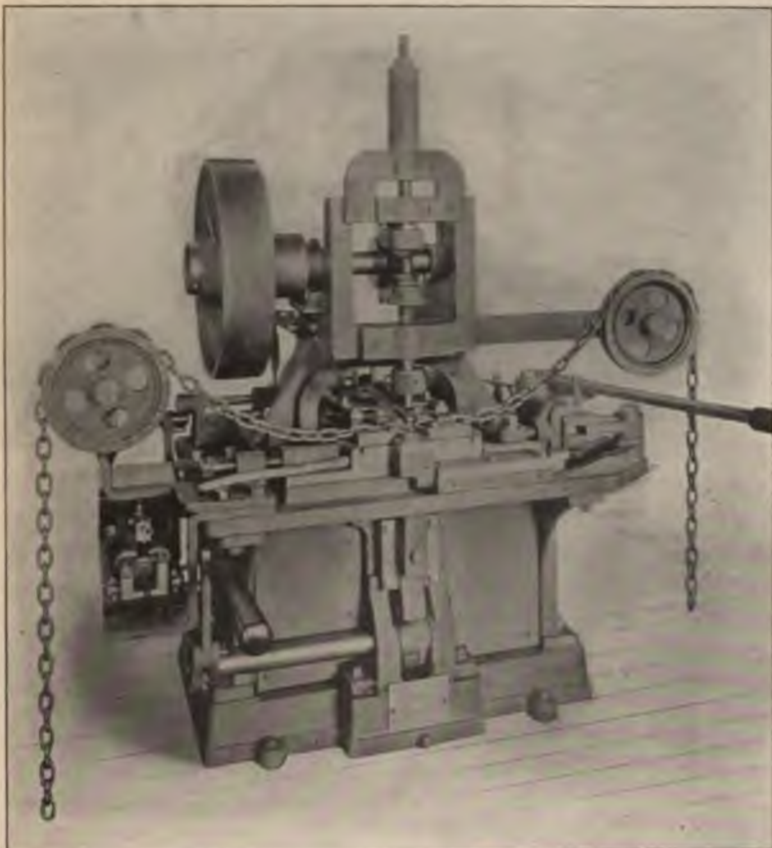
Adjustments. In the simpler types of electric welders, especially where the machine is designed to do a variety of work, perhaps of different forms or sizes of pieces, or both, the adjustments are usually manual; that is to say, the operations of clamping the pieces and applying the electric current and mechanical pressure are each controlled by the operator. In other cases, such as in the welding of copper or aluminium wire, the machine is, at least in part, automatic. The pressure is automatically applied and the welding current is cut off automatically upon the completion of the joint; the placing of the pieces in the clamps and the switching on of the current is, in this case, manually performed.

In other, more completely automatic, types, particularly adapted for rapid repetition of the same operation on identical pieces, the machine runs continuously, and its sequence of actions is definitely determined by the construction. In such cases a source of power, as by a belt, drives the machine, the movement so imparted having the effect of clamping the pieces as they are fed to the machine, putting on the current, applying the pressure, cutting off the current and releasing the pieces.

The mechanism which has been developed for these purposes displays, in many instances, much ingenuity. In these machines the duty of the attendant is limited to the mere placing of the pieces between the clamping jaws, just before they are clamped, and the work is characterised by rapidity and by uniformity of the results.

More completely automatic still are machines for the production of wire fencing and for the consecutive welding of the links of chains. In these the operation, once started, goes on uninterruptedly so long as the work holds out, or until the stock undergoing operation is exhausted. In the fence machines, of which fifteen are now in existence, galvanised iron wires are fed from reels parallel to one another, at distances apart depending on the mesh desired. These may correspond to the warp in weaving. Transversely to these, and at intervals corresponding to the mesh selected, are fed wires, cut from a reel, which transverse wires are the verticals in the finished fence itself and correspond to the weft in weaving. A series of small welders are automatically brought into operation to weld each transverse wire to the longitudinals where the two cross. This done, the web so formed moves forward, the operation repeats itself, and so on continuously. The welding is, in this case, practically instantaneous, and all of the movements of the machine are entirely automatic.

In this way it is possible for a single machine to turn out many thousands of feet of fencing per day with a width of mesh from 2 or 3 inches up. Less wire is used than where the joints are made by twists or loops, and the stability or fixedness of position of such joints as are made is much more assured.



ELECTRIC CHAIN-WELDING MACHINE.

Joints. While in most cases of electric welding the joint forms what is known as a butt weld, with a burr or extension of metal at the joint, which, according to conditions, is either allowed to remain or is forged down or dressed off, there is no difficulty in making lap welds electrically, and some of the recent work of the electric welder is of that character. While, too, the usual welding concerns pieces of the same metal, as iron to iron, steel to steel, or copper to copper, combination welds of different metals are made with facility in many cases, as when brass and iron are united.

In the working of high-carbon steels the usual precautions to prevent burning or injury to the metal are, of course, required;

ROLLS OF ELECTRICALLY-WELDED WIRE FENCE.

but, on account of the delicacy of heat control, they are more easily adopted.

Quite recently automatic chain welders have been put into use, and electrically-welded chain work will probably soon attain an importance not second to the other principal applications which have been briefly described.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for College, Civil Service, or Engineer's License. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

ELEMENTS OF ELECTRICITY.

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1. What is a magnetic substance?

2. Name the essential elements of a voltaic cell.

3. Upon what does the capacity of a condenser depend?

4. If it were desired to reduce the magnetism in a piece of steel, how could this be accomplished?

5. What is a loadstone?

6. What is the effect of self-induction upon the current?

7. How may the internal resistance of a cell be made of small amount?

8. Why does the compass needle point approximately north and south?

9. What is an electro-magnet?

10. Describe the process of electrotyping.

11. If one end only of a glass rod is rubbed with silk, will or will not the unrubbed end be charged by electricity, and why?

12. How may it be shown that the poles of a magnet are dissimilar?

13. Name a few applications of the heating effects of currents.

14. What is the source of electricity in the voltaic cell?

15. How may it be proved that the charges produced by frictional contact, although different in kind are equal in amount?

16. Give a definition of an accumulator.

17. What substance is the best conductor of electricity, and what one is the best insulator?

18. Suppose a piece of ivory and a piece of sulphur to be rubbed with silk. After a suspended pith ball has been touched

by the sulphur, will it be attracted or repelled by the ivory, and why?

19. What is an electroscope?

20. Explain how polarization is overcome in double fluid cells.

21. How may it be shown that the field of a magnet exerts its influence in certain definite directions?

22. What are the essential parts of a condenser?

23. How may it be shown that the charge upon a body resides upon its surface?

24. What is meant by the terms "primary coil" and "secondary coil"?

25. How does the construction of the relay differ from that of the sounder?

26. Why does attraction take place between a charged body and a conductor brought within its inductive influence?

27. In what manner does polarization decrease the power of a cell?

28. State three ways in which a current may be induced in a coil of wire.

29. What is meant by electrolysis? What is an electrolyte? An anode? A kathode?

30. Upon what main factors does the amount of charge induced by a charged body upon a conducting body depend?

31. State Joule's law.

32. How may it be shown that a wire carrying a current is surrounded by a magnetic field?

33. (*a*) When glass is rubbed by wool, which substance receives a positive charge, and which one a negative charge? (*b*) Does the charge produced on the glass exceed in quantity that produced on the wool?

34. Why is it possible to obtain very high electromotive forces by means of the induction coil?

35. Explain why there is no gain in energy by use of the electrophorus without a corresponding expenditure of work.

REVIEW QUESTIONS

ON THE SUBJECT OF

THE ELECTRIC CURRENT.

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1. (*a*) Explain what is meant by electromotive force. (*b*) What is its unit of measurement, and by what value is it represented?

2. (*a*) What is necessary to cause an electric current to flow? (*b*) What is meant by the strength of a current? (*c*) What is its unit of measurement, and by what value is it represented?

3. What is the unit of resistance and by what value is it represented?

4. Upon what three general factors does resistance depend?

5. What length of copper wire 2 millimeters in diameter will have the same resistance as 12 yards, 1 millimeter in diameter?
Ans. 48 yards.

6. State Ohm's law.

7. Two wires, whose resistances are respectively 28 and 24 ohms, are placed in parallel in a circuit so that the current divides, part passing through each. What resistance is offered by them to the current? Ans. 12.92 + ohms.

8. Fifty Grove's cells (E. M. F. = 1.8 volts) are in series, and united by a wire of 15 ohms resistance. If the internal resistance of each cell is .3 ohm, what is the current? Ans. 3 amperes.

9. (*a*) What is the unit of quantity of electricity? (*b*) Define the ampere-hour.

10. What is the power in watts when 4000 joules of work are done in 50 minutes? Ans. 1.33 + watts.

11. How many horse-power are equivalent to 83 kilowatts?
Ans. 111 + horse-power.

12. What is a shunt circuit?

13. A current of 18 amperes flows in a circuit whose resistance is 116 ohms. What is the voltage? Ans. 2088 volts.

14. The resistance of 312 feet of a certain wire is 2.08 ohms. What would be the resistance of 240 feet of the same wire? Ans. 1.6 ohms.

15. A total current of 56 amperes passes through a divided circuit having the resistance of its branches equal to 28 and 4 ohms respectively. What is the current in each branch?

Ans. In the 28-ohm branch, 7 amperes.
In the 4-ohm branch, 49 amperes.

16. What is the value of the current when 4 ampere-hours are delivered in a circuit in 20 minutes? Ans. 12 amperes.

17. (*a*) Define the joule. (*b*) Define the watt.

18. A 220-volt circuit supplies a current of 18 amperes. What is the power in kilowatts? Ans. 3.96 K. W.

19. If the resistance of a certain wire is 2.3 ohms per 1000 feet, how many feet of the wire will be required to make up a resistance of 17.8 ohms? Ans. 7739 + feet.

20. What is the resistance of a wire having a diameter of .2 inch if the resistance of the same length of similar wire having a diameter of .04 inch is 64.2 ohms? Ans. 2.56 + ohms.

21. Define specific resistance.

22. The resistance of a circuit is 1.8 ohms and the voltage is 110. What is the current? Ans. 61 + amperes.

23. A circuit contains a voltaic cell generating an electromotive force of 1 volt. Its electrodes are connected by three wires in parallel of 2, 3, and 4 ohms resistance respectively. The resistance of the cell is $\frac{1}{13}$ ohm. What is the current?

Ans. 1 ampere.

24. Eight cells each having an E. M. F. of .9 volt and an internal resistance of .6 ohm are connected in parallel, and the external resistance is 3.4 ohms. Find the current.

Ans. .26 ampere (approx.).

25. What quantity of electricity will be conveyed by a current of 40 amperes in half an hour? Ans. 72,000 coulombs.

26. The resistance of a circuit is 10 ohms, and the current is 33 amperes. What is the power in watts? Ans. 10,890 watts.

27. How many watts are equivalent to 14 horse-power?
Ans. 10.444 watts.

28. Five conductors having resistances respectively equal to 14, 3, 20, 31 and 8 ohms are joined in series, and the E. M. F. applied to the circuit is 50 volts. What is the current?
Ans. .65 amperes.

29. (*a*) Define conductance. (*b*) Define conductivity.

30. What is the resistance of 10 feet of annealed gold wire .001 inch in diameter at 32° F., if the resistance of an inch cube of the substance at 32° F. is .8079 microhm? Ans. 123 + ohms.

31. A copper wire has a resistance of 13.5 ohms at 43° F. What is its resistance at 57° F? Ans. 13.91 + or nearly 14 ohms.

32. What must be the resistance of a 220-volt circuit if the current is to be 70 amperes? Ans. 3.14 + ohms.

33. The E. M. F. applied to a circuit is 582, and the current is 8 amperes. A number of lamps connected in the circuit require a total drop of 522 volts. Find the resistance of the remaining portion of the circuit. Ans. 7.5 ohms.

34. A circuit is made up of six wires connected in parallel and having resistances of 72, 60, 21, 36, 40 and 210 ohms respectively. Find their joint resistance. Ans. 7.3 + ohms.

35. When a cell, which has an internal resistance of 1.39 ohms and an E. M. F. on open circuit of 1.32 volts, is supplying a current of .29 ampere, what is its available E. M. F.?
Ans. .92 volts (approx.).

36. With a current of 20 amperes how much time will be required to deliver 4,000 coulombs. Ans. 3 minutes, 20 seconds.

37. The voltage of a circuit is 103 and the current is .5 ampere. What energy is expended in a minute and a half?
Ans. 4635 joules.

38. The resistance of a coil of platinoid wire at 98° C. is 8014 ohms. What resistance would the coil have at 18° C.?
Ans. 2962 ohms (approx.).

39. What is the resistance of 28 feet of No. 6 (B. & S.) pure copper wire at 90° F.? Ans. .0118 + ohm.

40. If a resistance of 116 ohms be inserted in a circuit, and it is desired to maintain a constant current of 9.6 amperes, how much must the voltage of the circuit be increased?
Ans. 1113 + volts.

41. When a current of 14 amperes flows in a circuit whose resistance is 54 ohms, what energy in kilowatt-hours is expended in half an hour? Ans. 5.292 kilowatt-hours.

42. Explain the difference between the kilowatt and the kilowatt-hour.

43. What number of calories will be developed by a current of .14 ampere flowing through a wire of 4 ohms resistance for 5 minutes? Ans. 5.6 + calories.

44. The voltage applied to a circuit in which three wires are connected in parallel is 107. Find the current in each branch if the separate resistances are respectively 43, 9 and 25 ohms.

Ans. In 43-ohm branch, 2.4 + amperes.
In 9-ohm branch, 11 + amperes.
In 25-ohm branch, 4.2 + amperes.

45. How many horse-power are equivalent to 1048 watts? Ans. 1.4 + horse-power.

46. If the resistance of 1 foot of annealed silver wire .001 inch in diameter at 32° F. is approximately 9.02 ohms, what is the resistance of 4 miles of the wire .01 inch in diameter at a temperature of 90° F.? Ans. 2137 + ohms.

47. Twenty large Leclanche cells (E. M. F. = 1.5 volts, resistance = 0.5 ohm each) are in a circuit in which the external resistance is 10 ohms. Find the strength of current which flows (*a*) when the cells are joined in series; (*b*) when all the cells are in parallel; (*c*) when there are 2 files each having 10 cells in series; and (*d*) when there are 4 files each having 5 cells in series.

Ans. Amperes (*a*) 1.5; (*b*) 0.149; (*c*) 1.2; (*d*) 0.706.

48. How many kilowatts are equivalent to 150 horse-power? Ans. 111.9 K. W.

49. If a current of 9.3 amperes flows when the voltage of a circuit is 110, how much resistance must be inserted in the circuit to reduce the current to 3.4 amperes? Ans. 20 + ohms (approx.).

50. A current of 26 amperes is flowing in a circuit which has a voltage of 500. What is the equivalent power in mechanical units? Ans. 17.4 + horse-power.

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRICAL MEASUREMENTS.

1. What is the distinction between fundamental and derived units?

2. What is meant by the dimensions of a physical quantity?

3. Describe a method of calibrating ammeters.

4. Explain why a voltmeter should have a high resistance and an ammeter a low resistance.

5. The ohm is equal to how many absolute units of resistance?

6. Upon what factors does the deflection of a galvanometer needle depend?

7. How may the resistance of a water rheostat be varied?

8. It is known that a coil of wire has an approximate resistance of 200 ohms, and it is desired to find its correct resistance tothe first decimal place by using the Wheatstone bridge. What should be the ratio of the bridge arms?

9. State the difference between the two general classes of galvanometers.

10. Give the advantages of the D'Arsonval galvanometer.

11. How many B. A. ohms are equal to 96 International ohms?

12. A galvanometer has a resistance of 5940 ohms and its shunt 60 ohms. What is the multiplying power of the shunt?

13. (*a*) What is the value of the kilowatt-hour? (*b*) How

many kilowatt-hours are expended by a current of 60 amperes in 8 hours and 45 minutes, the E. M. F. being 110 volts?

Ans. 24.75 kilowatts-hours.

14. When using the Wheatstone bridge why should the galvanometer key be closed after and opened before the battery key?

15. Explain why an astatic pair of needles is very sensitive to a slight current when the coil carrying the same is wound about one of the needles.

16. How may a galvanometer be used as a voltmeter?

17. Explain the principle of a differential galvanometer.

18. The E. M. F. of a Leclanche cell on open circuit as given by a voltmeter was 1.64 volts. After closing the cell through a certain external resistance, its E. M. F. fell to 1.10 volts, the current being .4 ampere. What was the resistance of the cell?

19. Describe the Weston voltmeter.

20. In Fig. 21 suppose the reversing key to be changed, and that a balance is obtained when $M = 1$, $N = 100$, and $P = 3{,}000 + 400 + 200 + 30 + 3 + 2$. What is the value of the resistance measured?

21. What are the disadvantages of electromagnetic ammeters?

22. In testing the insulation of a circuit by the voltmeter method, the voltmeter reading was 4.5 volts and the applied E. M. F. 220 volts. What was the insulation resistance in megohms, the voltmeter resistance being 17,000 ohms?

23. In making a high resistance measurement by the direct deflection method, the deflection obtained with .1 megohm resistance was 250 divisions. The unknown resistance gave a deflection of 20 divisions. In the former case the multiplying power of the shunt was 1000, and in the latter the shunt circuit was open. What was the unknown resistance?

24. What method should be used in testing the insulation of a 1,000 volt circuit?

25. (*a*) Describe an electrostatic voltmeter. (*b*) Give its advantages and disadvantages.

26. How is quantity determined by the Edison chemical meter?

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC WIRING.

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1. Under what conditions is "fishing" of wires allowed? Explain the process.

2. In conduit work how many quarter bends are allowed from outlet to outlet?

3. Tell what you can about flexible cord.

4. Where should cut-outs or circuit breakers be located for house wiring?

5. What must be the voltage of the dynamo in order to supply lamps or motors in a 110-volt system, with a 5 per cent loss?

6. What is a cull pole?

7. When a high-potential machine has its frame grounded, what precautions should be taken for the protection of the attendant?

8. What can you say about the rules to be followed when installing wires?

9. Give a rule for the proper depth to which to set a pole.

10. How would you ground a dynamo frame?

11. What is the least allowable radius of curvature in conduit work?

12. State the rule to be followed in starting or stopping motors.

13. What is the objection to putting the ground wire from a lightning arrester into an iron pipe?

14. State briefly the requirements for interior wiring in the case of series arc lighting work.

15. Describe the care which should be given to the brushes to keep them in good condition.

16. Describe a piece of apparatus for protecting the armature of a motor.

17. Why should standard rubber-covered wires be used in conduit work?

18. What is the least space that should be left between

(a) The switchboard and the floor?

(b) The switchboard and the ceiling?

19. What is the largest permissible current dependent upon one cut-out?

20. What insulation resistance is required between gas pipe attachments and an insulating joint?

21. Under what conditions should the frame of a dynamo be grounded?

22. What kind of wire must be used in moulding work?

23. What can you say about wiring for damp places?

24. In which direction does the armature of a generator usually revolve?

25. Determine by use of table on page 40 what size of wire should be used to supply 75 16-candle-power incandescent lights, 110 volts, loss 3 volts, and at a distance of 200 feet to center of distribution.

26. What is the best material for poles?

27. Describe a method of setting the brushes so that they will be diametrically opposite each other.

28. In splicing two pieces of wire, what precautions are necessary?

29. What size of wire will be required to supply a 10-horse-power motor on a 500-volt circuit at a distance of 200 feet with 15 volts' drop?

30. What current is taken by the motor referred to in Question 29?

31. Describe the connections for the three-wire system.

32. Determine by formula the size of wire for 40 16-candle-power incandescent lights on a 110-volt circuit with 5 volts' drop at a distance of 150 feet.

33. Under what conditions may the neutral of a three-wire system be grounded?

34. What is the smallest sized wire that should be used for interior wiring?

35. In case of hot box, what should be done before deciding that it is necessary to shut down?

36. What are the objections to using excessive voltage for incandescent lighting circuits?

37. Describe with sketch the direct-current ground detector.

38. If iron pipe be used with alternating current, should the two or more wires of a circuit be placed in the same conduit, or in separate conduits?

39. In wiring a building, what is the least insulation resistance allowed between conductors and the ground for 100 amperes?

40. If a dynamo is to be run in parallel with another machine and its polarity is wrong, how can this be remedied?

REVIEW QUESTIONS

ON THE SUBJECT OF

THE ELECTRIC TELEGRAPH.

1. Give examples of the different kinds of messages.
2. Wherein does the construction of the relay differ from that of the sounder? Why?
3. How many copies are made of train orders? Why?
4. How does the count of a government message differ from that of an ordinary message? Of a cable message?
5. How could signals be transmitted without a key?
6. (a) What is Code telegraphy? (b) Give a brief example.
7. In copying a message why is the destination placed on a line by itself?
8. (a) Give three points of difference between commercial and railway telegraphy. (b) What is the important feature of a railway operator's work?
9. In the switchboard, what is the only means of electrical connection between the bars and discs?
10. Name the apparatus used in a one-wire office.
11. What are the parts of the sounder?
12. (a) What are the six different classes in which the signals of the Morse code can be arranged? (b) Give examples.
13. What part of the relay does the work of a key for the local circuit?
14. (a) In the Auto-Alphabet instrument what determines the movement of the local points? (b) What care must be taken with regard to them?
15. (a) What are the elements of the Morse code? (b) Which is the time unit?
16. (a) How would you transform the local circuit into a learner's outfit?

REVIEW QUESTIONS

ON THE SUBJECT OF

THE ELECTRIC TELEGRAPH

1. What test can be applied to make sure that the armature of an electromagnet does not touch the core?

2. What is the essential feature of the Phonoplex? How are the signals produced?

3. What are the principal uses of the dynamo in telegraphy?

4. What two forms of apparatus are combined to form the quadruplex?

5. (*a*) What is static electricity? (*b*) How are the effects of the discharge on the duplex relay overcome?

6. If the transmitters are open in the Stearns duplex, admitting a small proportion of each battery to line, how can the effect on the relay be overcome?

7. What is the only means of electrical connection in the switchboard between the rows of discs and the strips?

8. How is the home relay in the Stearns duplex made unresponsive to the home battery?

9. What is the function of the transmitter in the quadruplex as compared with that of the pole changer?

10. What is the rule for determining the polarities in a core around which a current is passing?

11. What would be the resistance of six four-ohm sounders in series? In multiple?

12. What is a rheostat and what part does it play in the duplex?

13. How could a test of the short and long end of the quad battery be made without a meter?

14. What is meant by a differential relay?